EMCal simulation Summary and Plan

Outline: sPHENIX EMCal Overview • Projective design update • Other simulation tasks

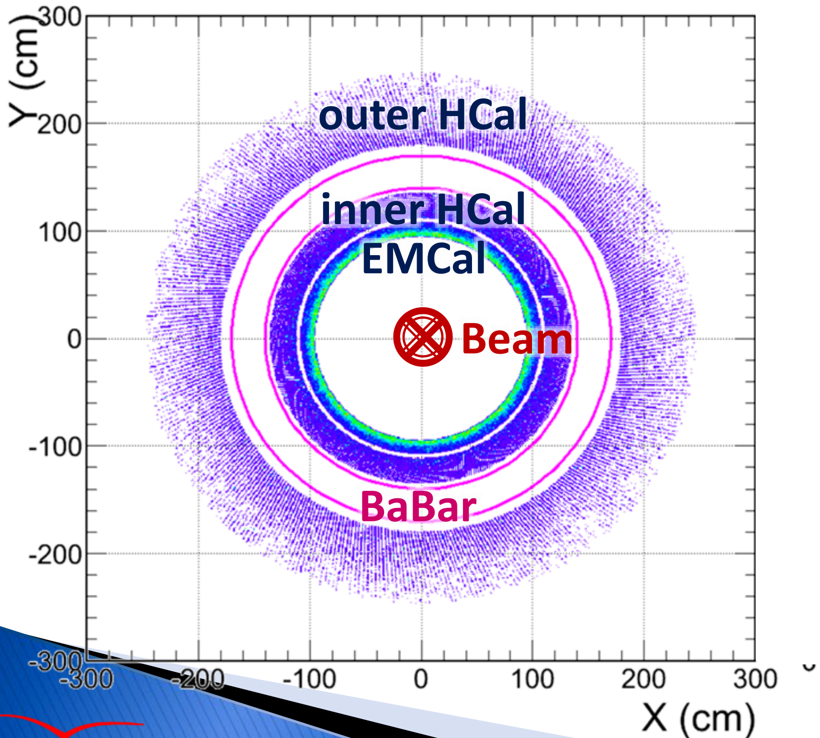
Jin Huang (BNL)

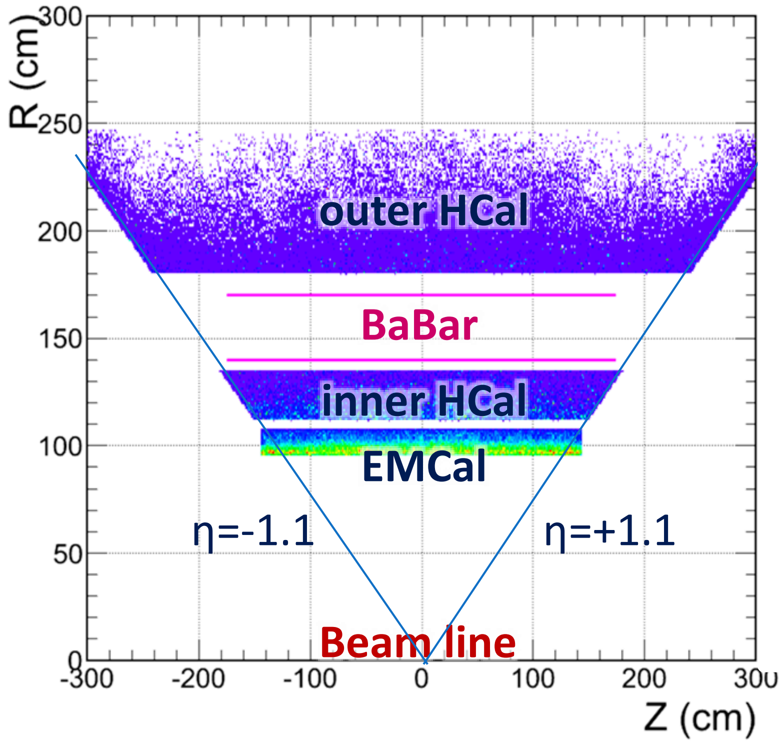
Brief summary for proposal simulation studies

sPHENIX Calorimeters

- EM calorimeter (EMCal) : 18 X_0 SPACAL
- Inner hadron calorimeter (inner HCal) : 1 λ_0 Cu-Scint. sampling
- BaBar coil and cryostat. (BaBar): 1 X_0
- Outer hadron calorimeter (outer HCal) : 4 λ_0 Steel-Scint. sampling

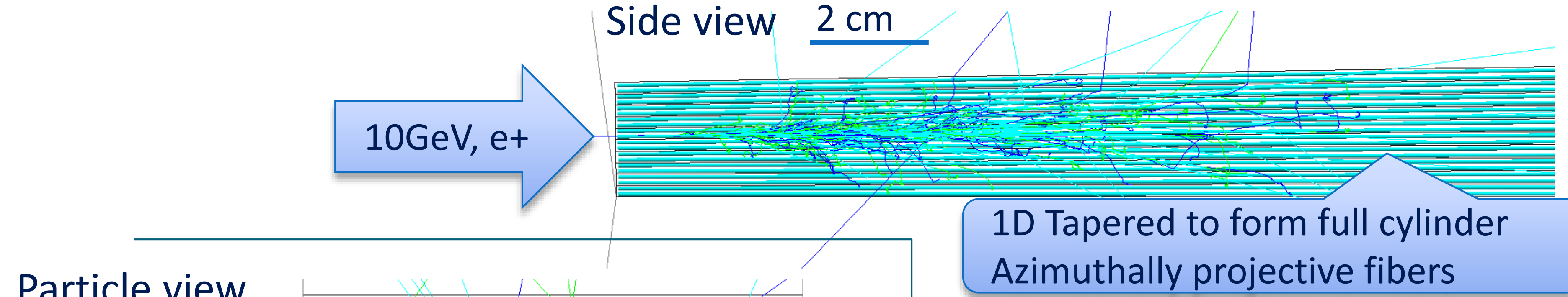
Calorimeter energy distribution in full event central AuAu collisions and realistic magnetic field

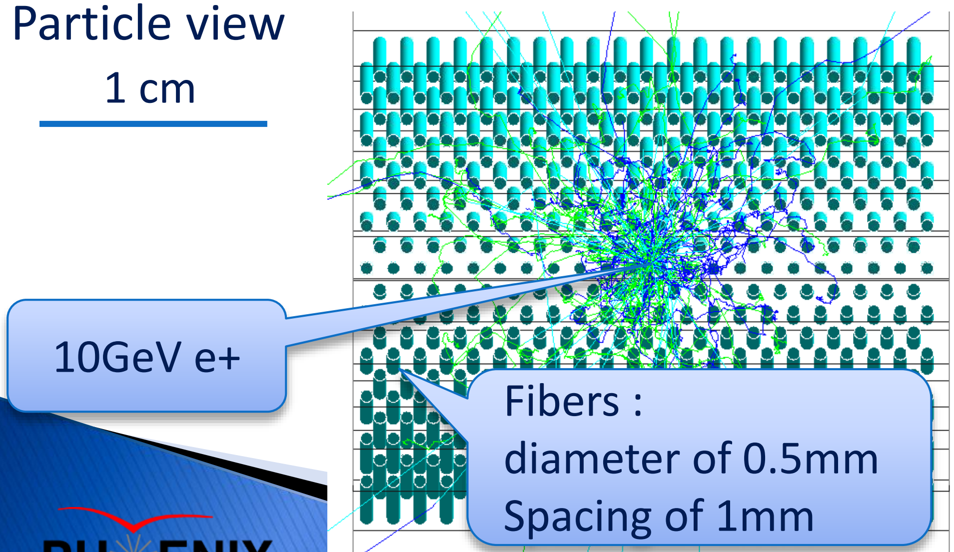




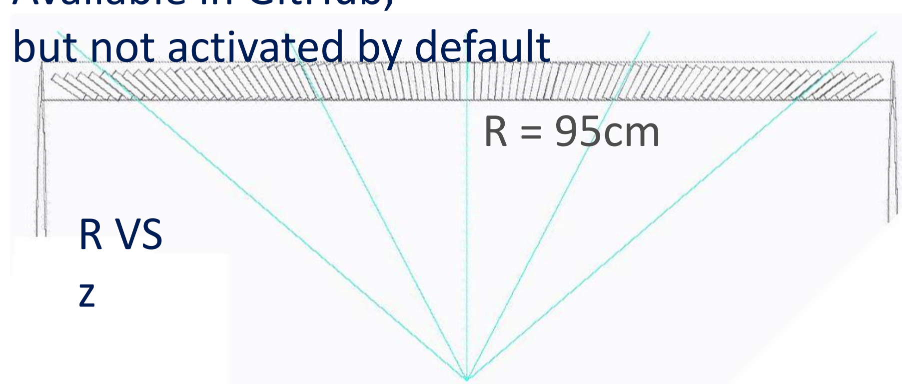
SPACAL simulation

- SPACAL implemented in sPHENIX simulation framework
  - Thanks to reference model from A. Kiselev (EIC taskforce & EIC RD1)
- 10 GeV electron shower in a single SPACAL module shown
- Covered full azimuthal and |η|<1.1 in sPHENIX
- 1-D projective in azimuth. Non-projective in polar direction

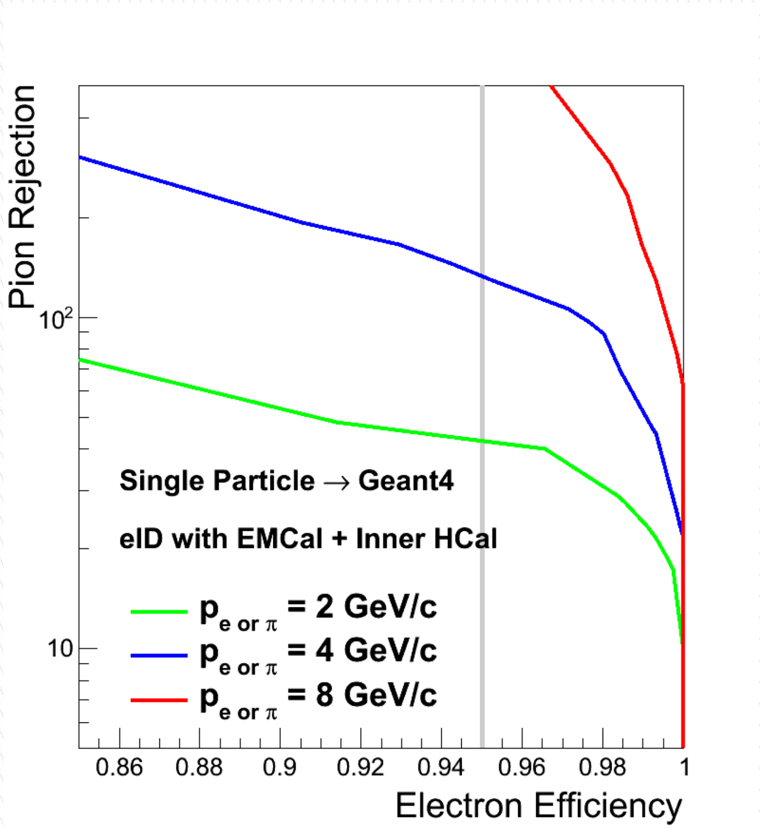




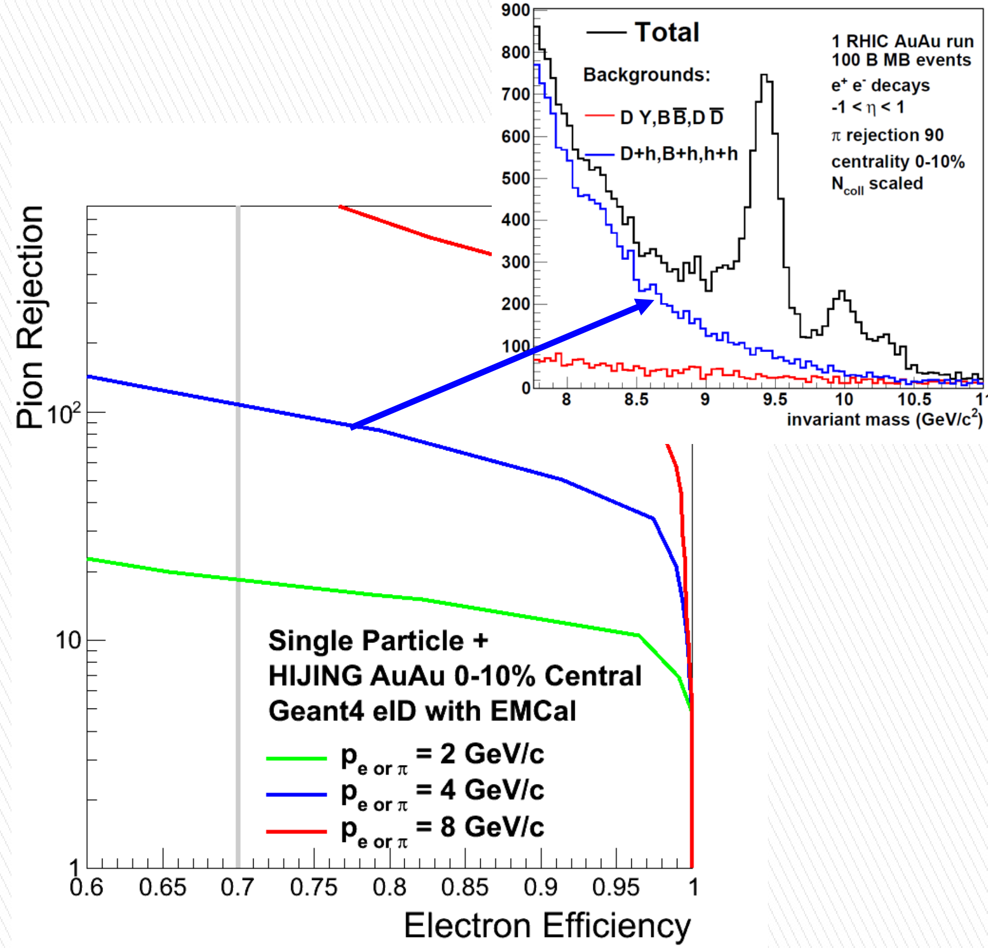
A polar projective design in Geant4
Available in GitHub,
but not activated by default



Compile everything together for barrel electron ID



pp/ep electron ID (EMC+HCAL)



Central AA electron ID (EMC Only)

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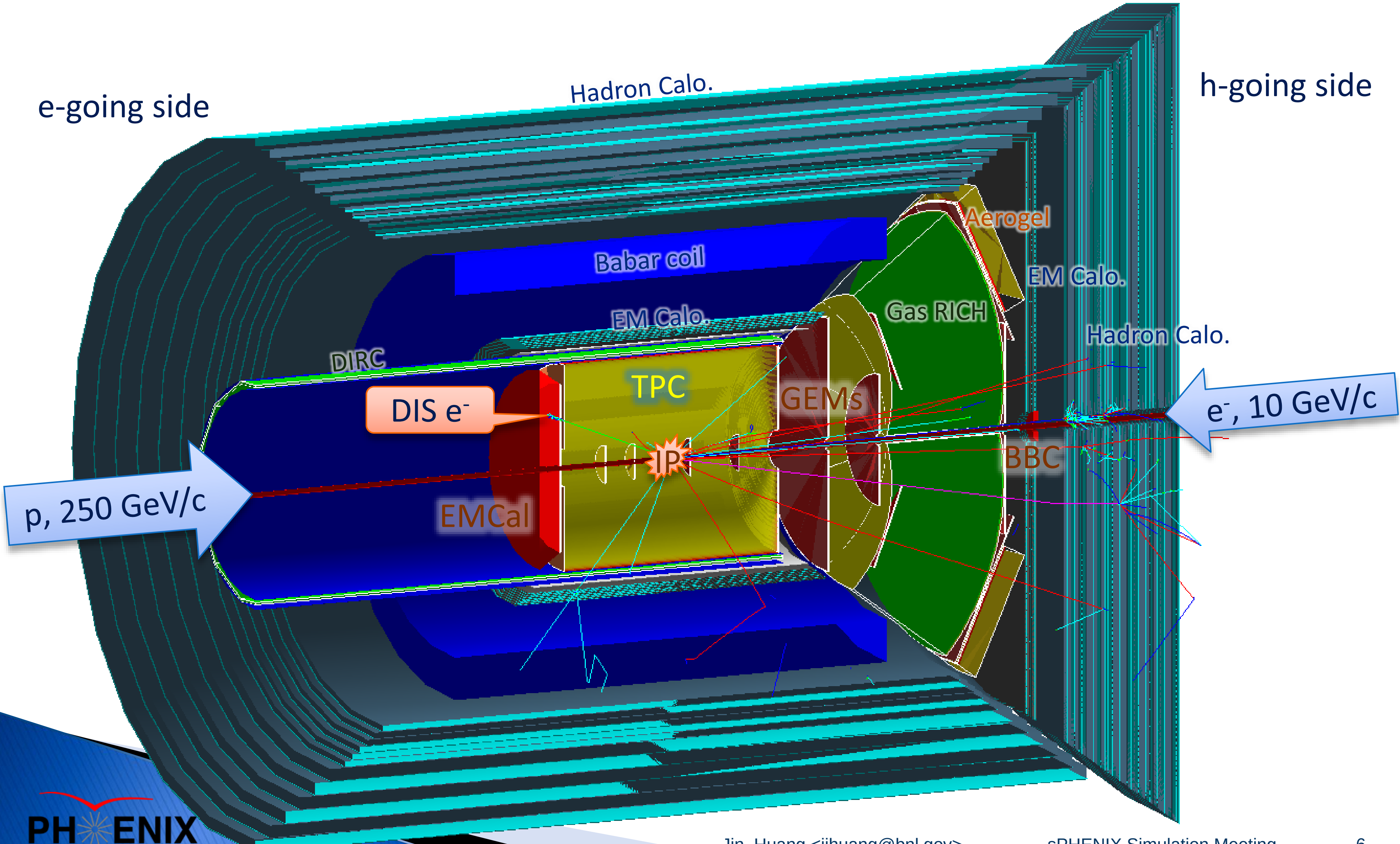
Calorimeters in e/fsPHENIX

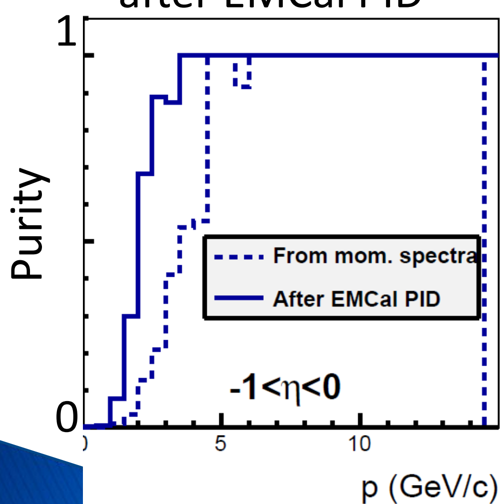


Use of calorimeter for EIC physics

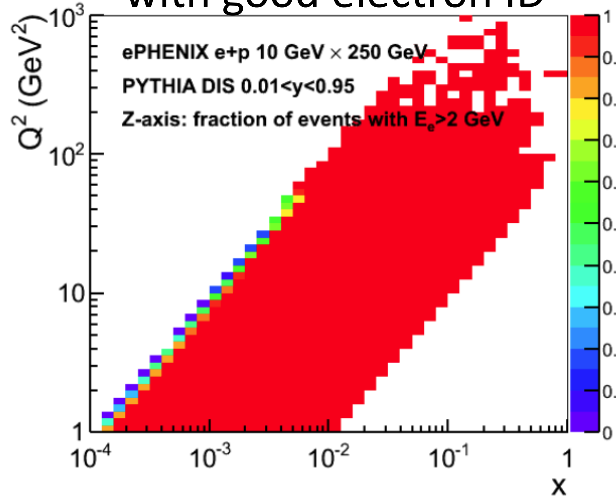
- Electron identification (e-EMC, barrel EMC)
- Electron kinematics measurement (e-EMC, barrel EMC)
- DIS kinematics using hadron final states (barrel EMC/HCal, h-EMC/HCal)
- Photon ID for DVCS (All EMC)

From Sasha and Karen using parameterized performance

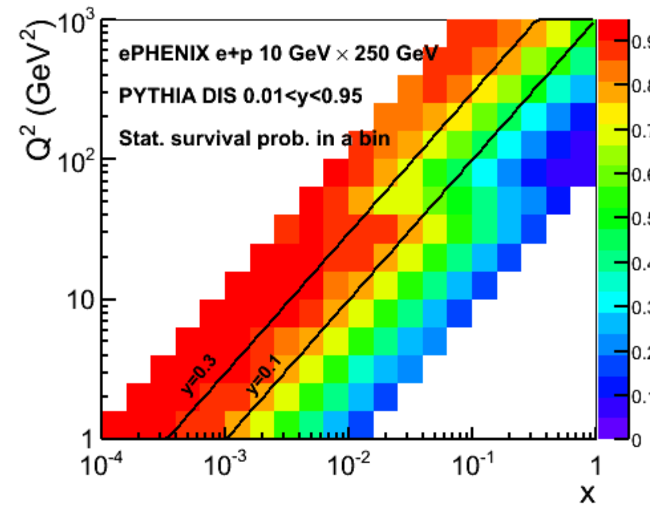
Electron purity after EMCal PID



Fraction of DIS event with good electron ID



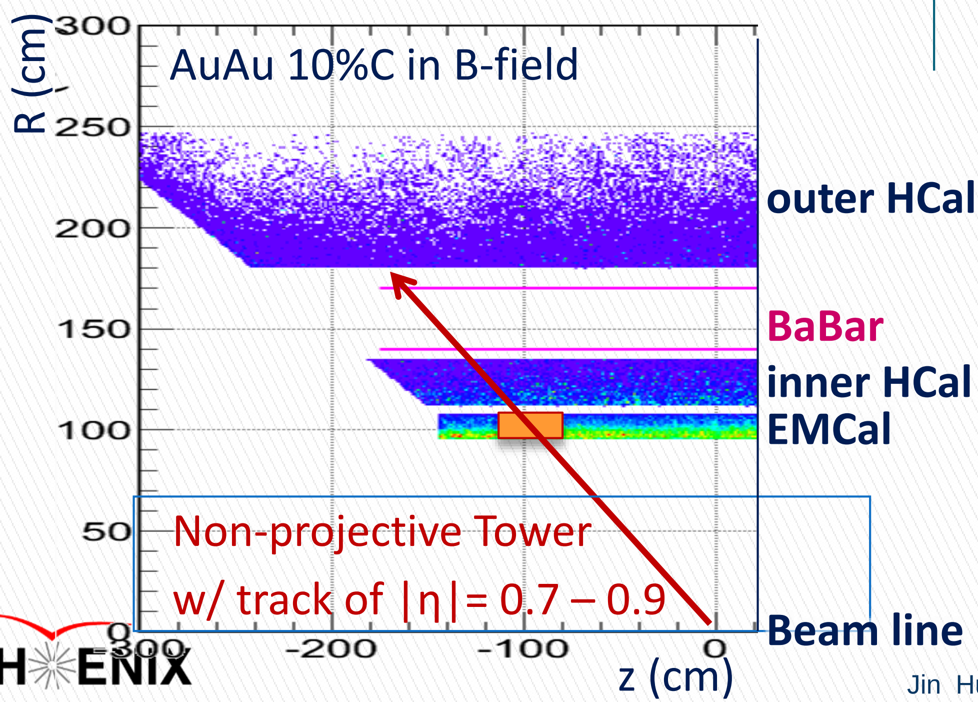
DIS kinematics survivability
Electron kinematic method



Recent progress on Projective EMCal design

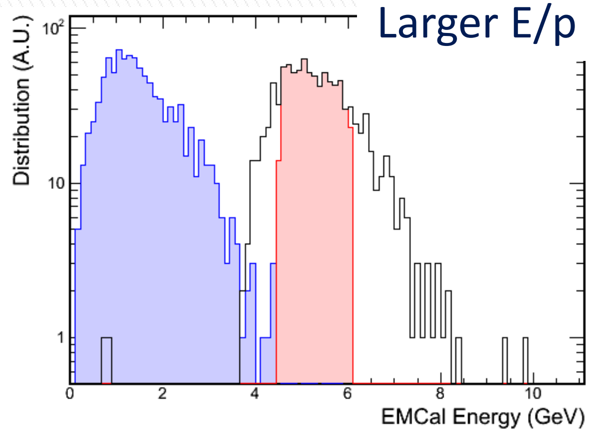
Larger pseudo-rapidity in central AuAu : under study

- Out of the box: larger |η|→ larger background
  - Longer path length in calorimeter
  - Covers more non-projective towers
- to improve
  - **Better estimate of the underlying background event-by-event (improve x1.5)**
  - **Use (radially) thinner ECal (improve x2)**
  - **Possibilities for projective towers?**



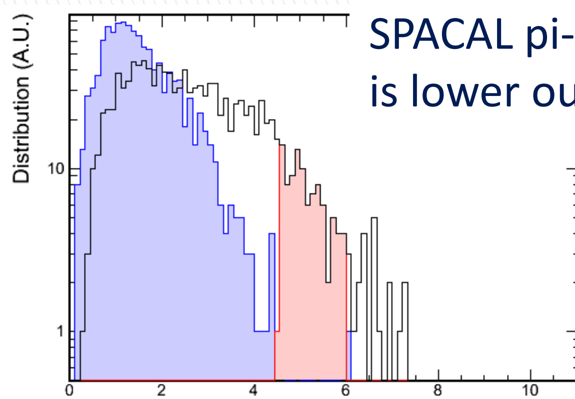
- all events (w/ embedding)
- with EMCal E/p cut (w/ embedding)
- Hijing background (AuAu 10%C in B-field)

SPACAL e-
Larger E/p cuts

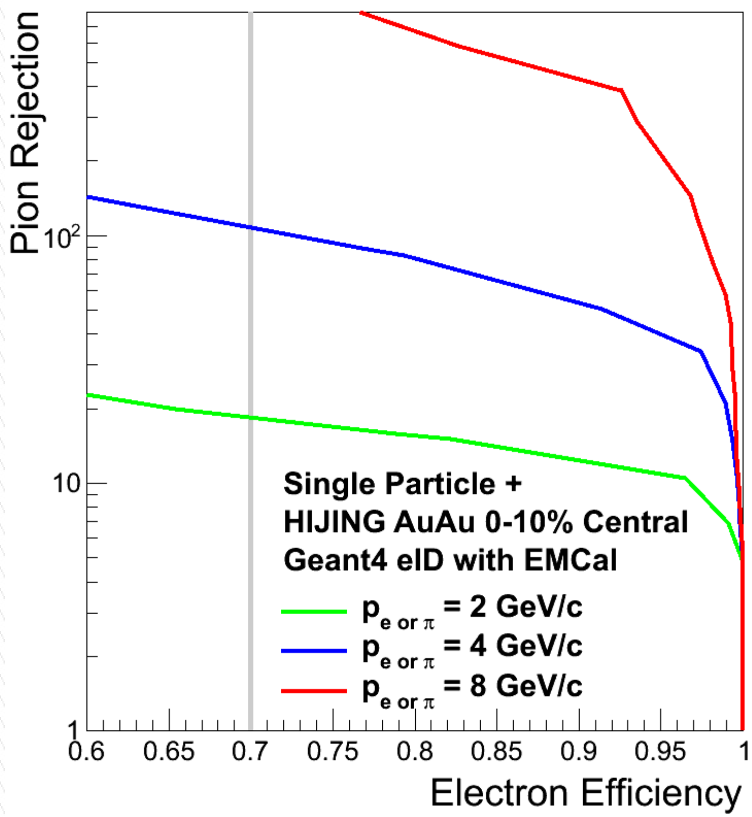


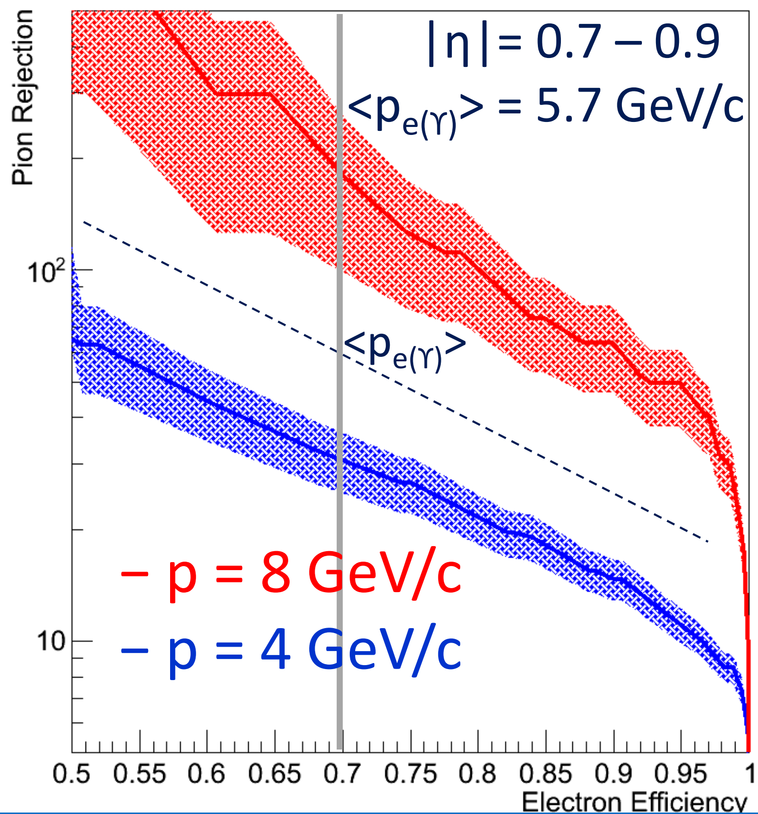
Out of box rejection ~10:1

SPACAL pi- rejection
is lower out of the box



Comparison for EID performance





Central rapidity
$|\eta|< 0.2$

Forward rapidity
$|\eta|= 0.7 – 0.9$

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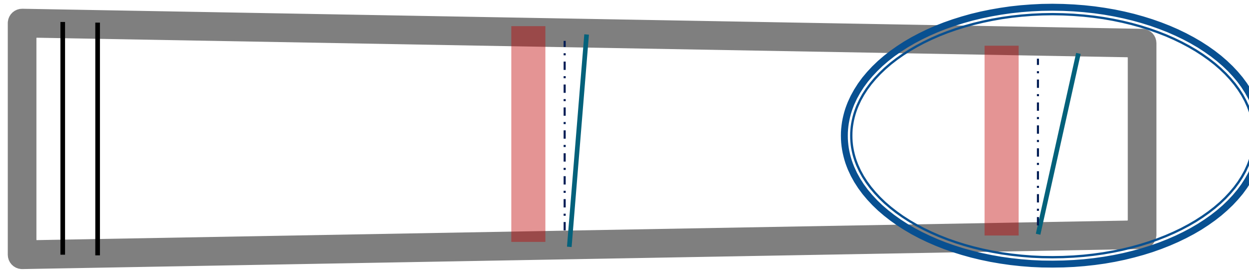
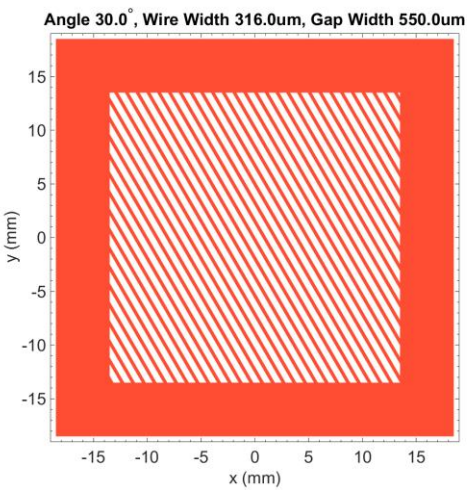
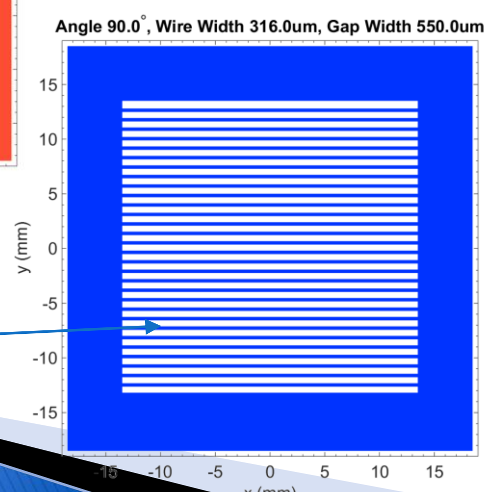
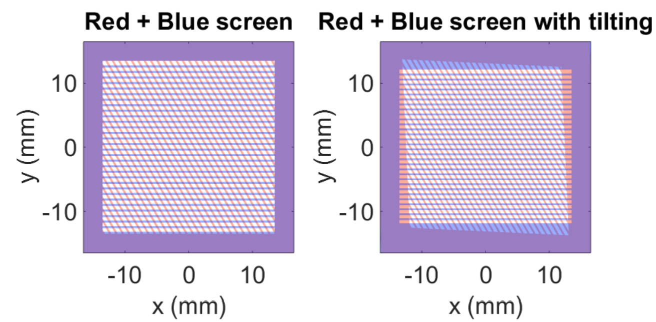
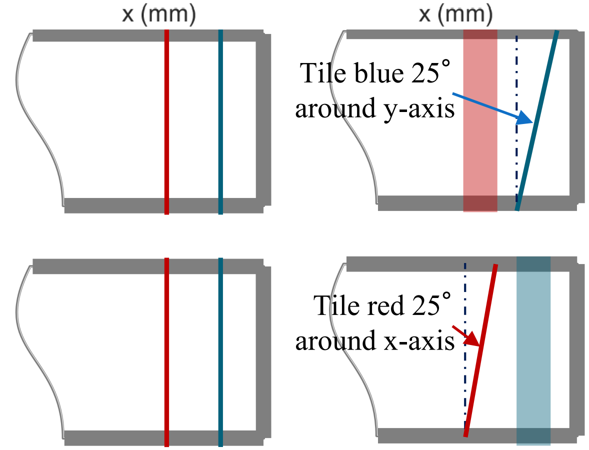
One R&D direction: world first 2-D tapered SPACAL



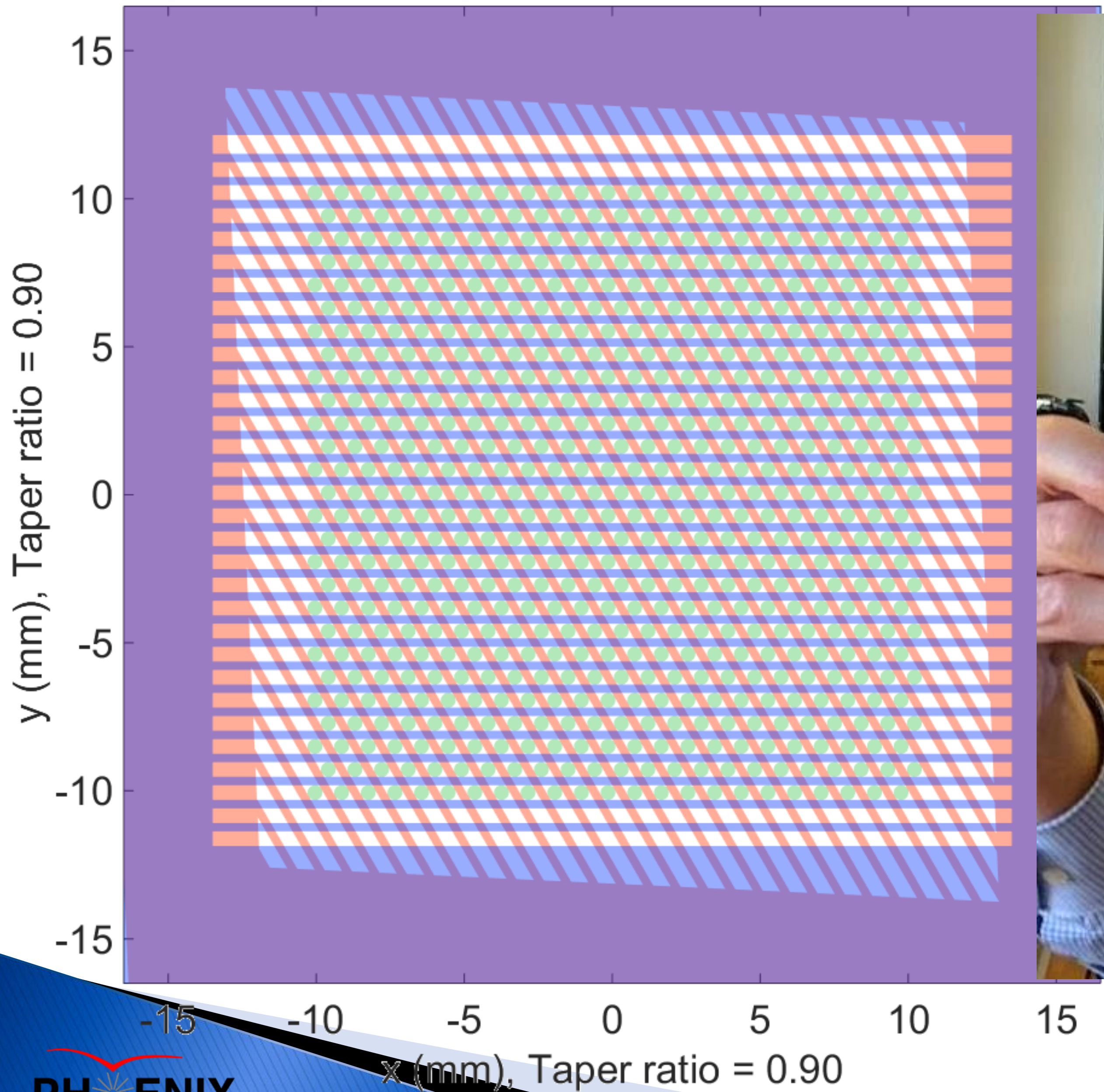


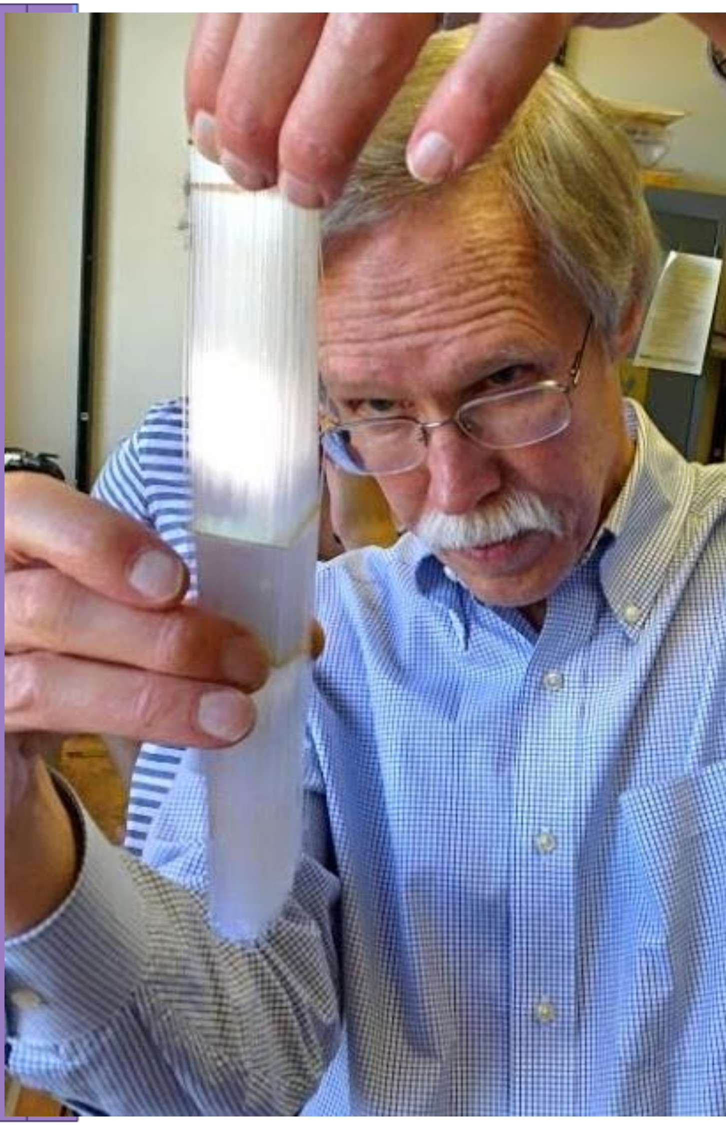




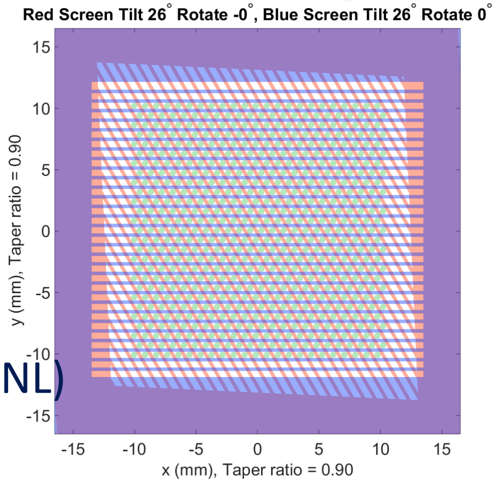


Red Screen Tilt 26° Rotate -0°, Blue Screen Tilt 26° Rotate 0°



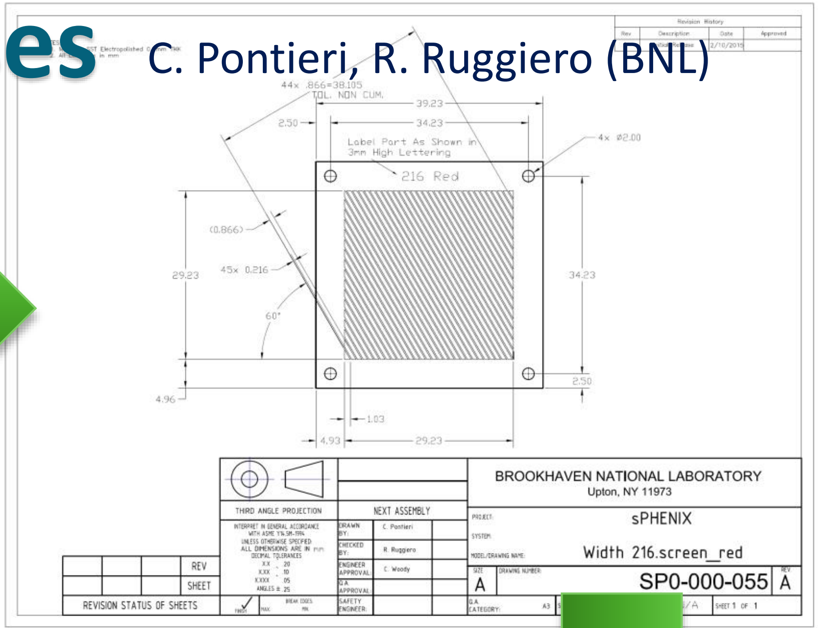


Recent R&D progresses

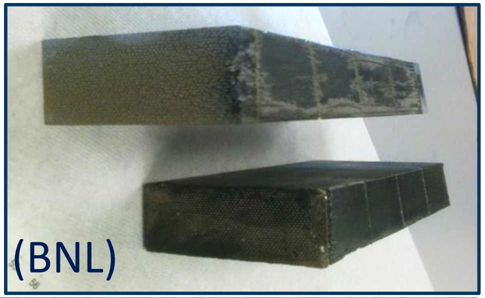


J. Huang (BNL)

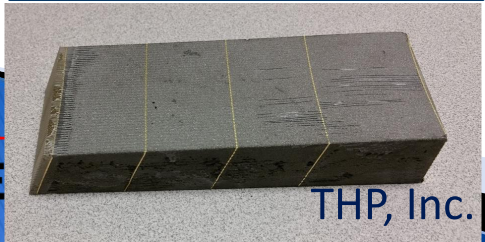
C. Pontieri, R. Ruggiero (BNL)



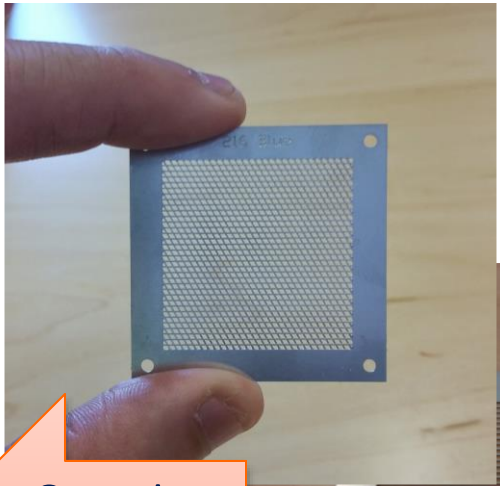
A. Sickle, V. Loggins (UIUC)



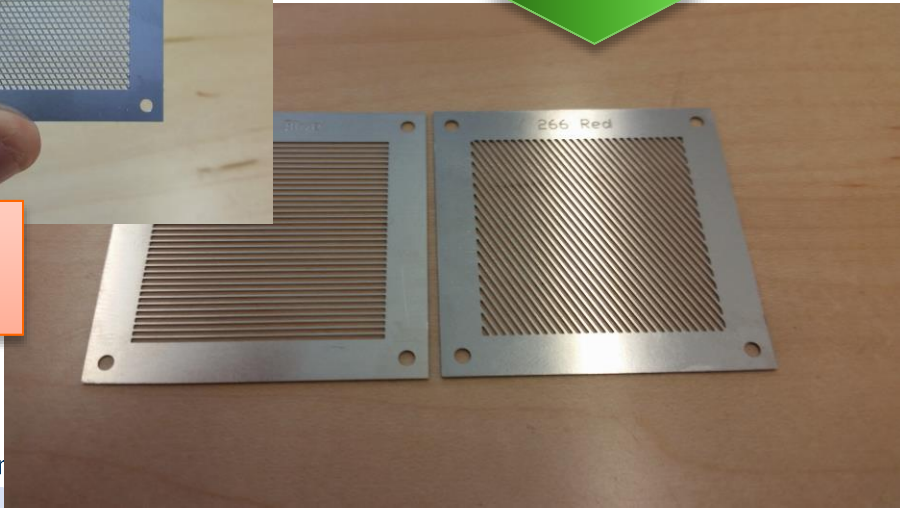
S. Stoll (BNL)



THP, Inc.

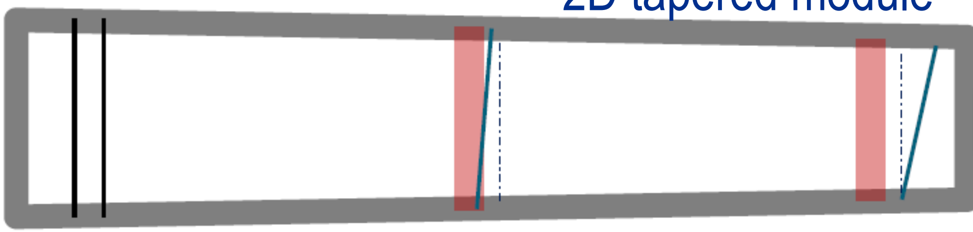


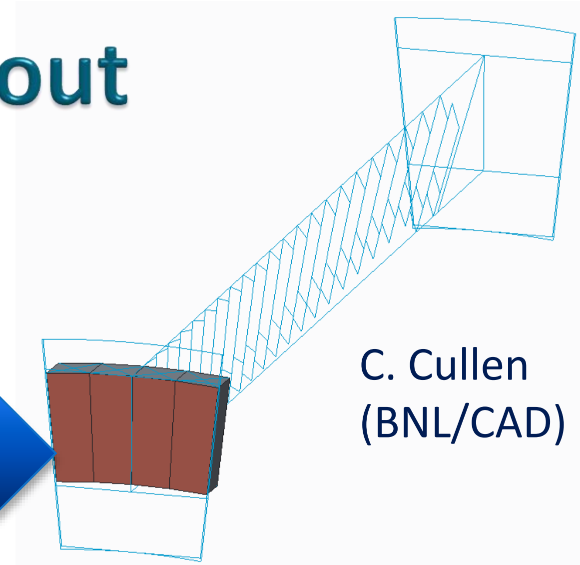
Tech-Etch



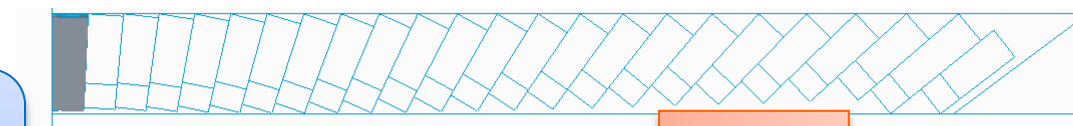
On-going R&D

On-going: 2-D projective layout in CAD and simulation



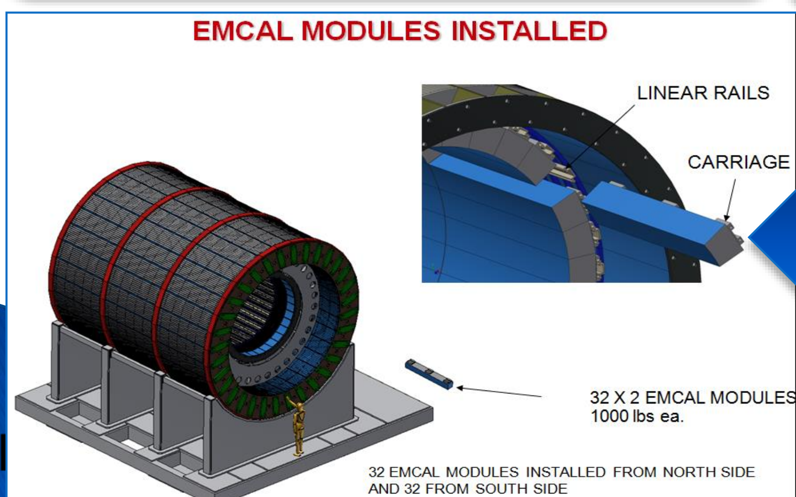


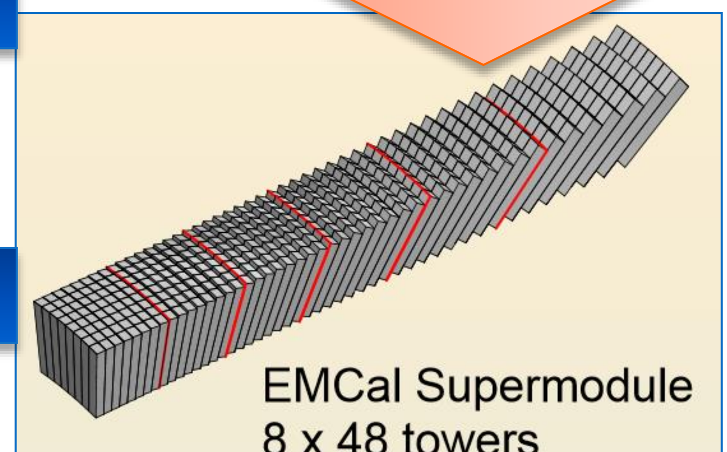
C. Cullen
(BNL/CAD)



Simulation for 2-D projective EMCal:
Plan to import the CAD geometry into sPHENIX Geant4

On-going





(Not yet updated to 2x2 block)

Other simulation tasks

- Geometry exportation
- Energy leakage
- Sampling fraction variation
- Detection response model
- Shower shape analysis

Export of tower geometry

- Once the tower structure is detailed implemented in Geant4, the block -> eta,phi mapping would become non-trivial.
- Similar problem happens for SVX ladder and HCal tiles
- One option to carry these information from Geant4 -> Reco universe is through ROOT::TGeoManager (similar approach for PHENIX/FVTX)
  - Produce a copy of the detector geometry in TGeoManager (in less detailed level) by PHENIX G4 detector modules.
    - E.g. an EMCal block can be described by TGeoTrd2 (3D trapezoid) in TGeoManager
  - Assign each readout unit with a unique ID number
  - A geometry descriptive object in DST/T1 tree link the ID to a 3D object in TGeoManager
  - Save both TGeoManager and geometry descriptive object in DST, and used in reconstruction
- Will test this approach as part of work to implement 2D projective EMCal in G4

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Detailed detection response Model

- In current simulation of sPHENIX calorimeters, energy from calorimeter is sum of total energy deposition or ionization energy deposition
- In post-CD0-stage, more realistic simulations, several experimental factors need to be considered, including ionizing energy loss, scintillating light modeling, transportation of photons, and noise in SiPM
- Scintillating light modeling ready for CVS submission: scintillation light saturation modeling [Birk, Phys. Rev. 84, 364, 1951]

$$Light\ Yield \propto \frac{\frac{dE}{dx}}{1 + kB\ \frac{dE}{dx}}$$

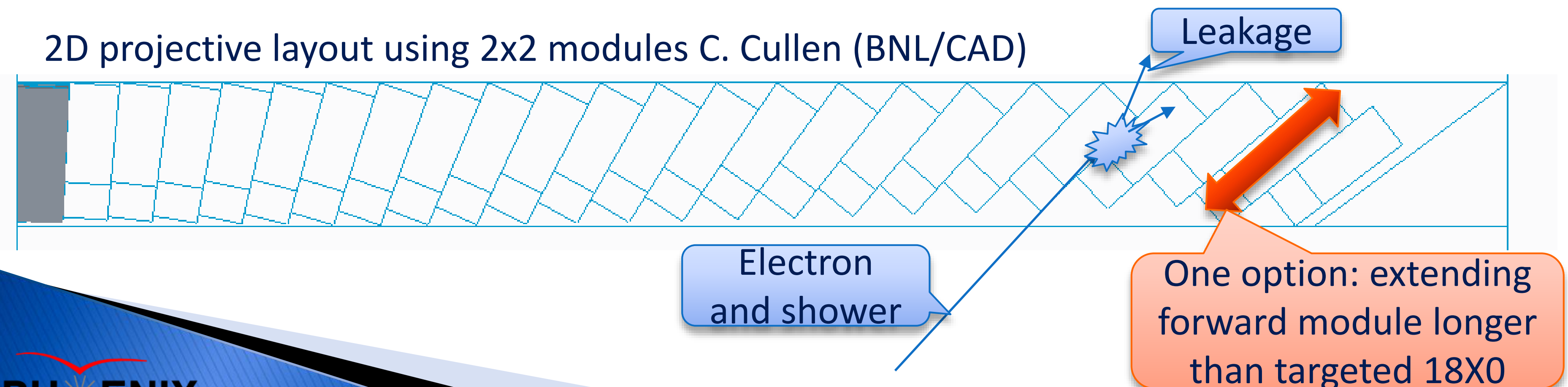
k_B~ 0.126 mm/MeV [arXiv:1106.5649v2]

Need to update the performance plot with these new considerations

Rear leakage

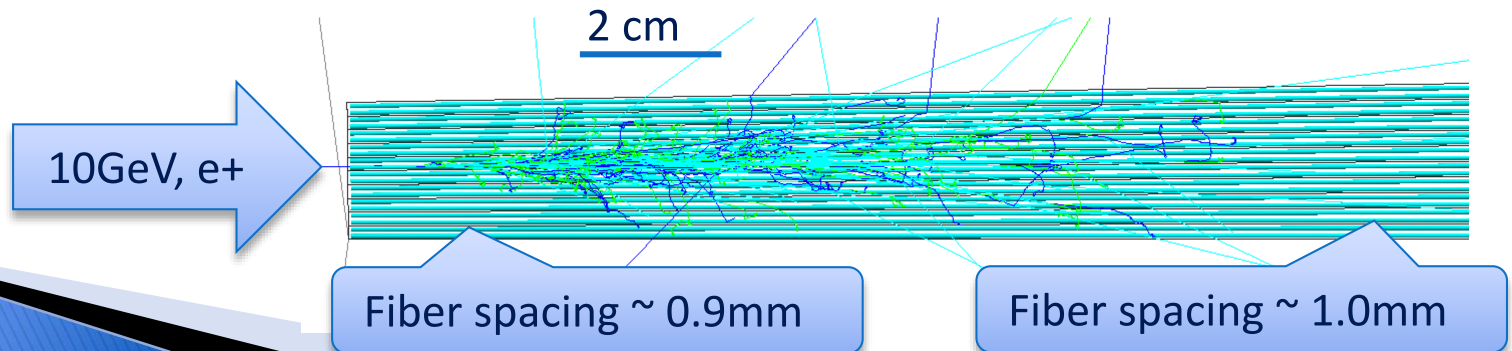
- As in many block calorimeter, steps formed by staging blocks leads to position dependent rear leakage
- Already observed in 1x1 block during Martin's simulation by scanning response along z
- Remedy?
  - Use 1x1 module towards larger eta region, with higher production complexity
  - Make the forward module longer, so the overlap region remain the nominal ~18 X0
- Need to quantify this effect and remedies in Geant4
  Volunteer welcomed!

2D projective layout using 2x2 modules C. Cullen (BNL/CAD)



Sampling fraction variation

- In the current design 2D tapering in SPACAL comes with the cost that fiber density changes from front to back side of the SPACAL module by 10-20%
- This leads to a larger constant term in energy resolution
- Is this important comparing to 12%/sqrt(E) statistical term of energy resolution?
- Need to evaluate for both sPHENIX (eID performance, direct -Gamma) and EIC case (eID performance, kinematic smearing)
- Volunteer welcomed



Tower-by-tower shower shape analysis

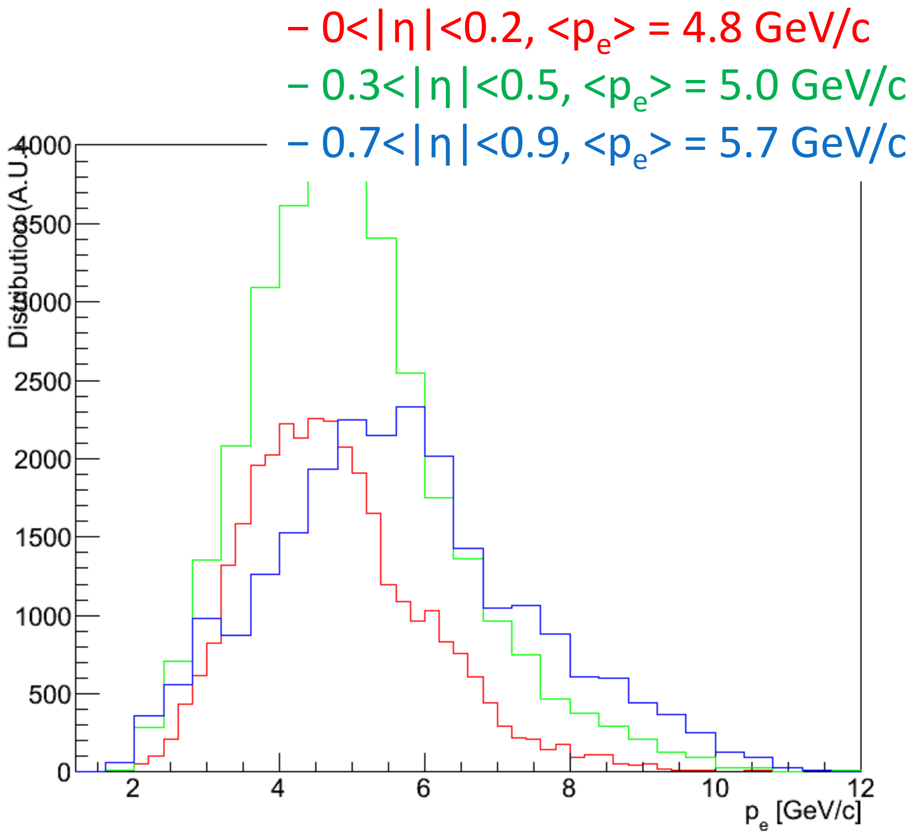
- Hadron shower extend larger than EM Shower, which provide additional handle on electron ID
- Track based cluster finding to fully use the information
- Exploring modern machine learning algorithm (e.g. Boosted decision tree or support vector machine) to evaluate PID based tower response around primary track
- How does it work in heavy ion environment?
- Volunteer welcomed

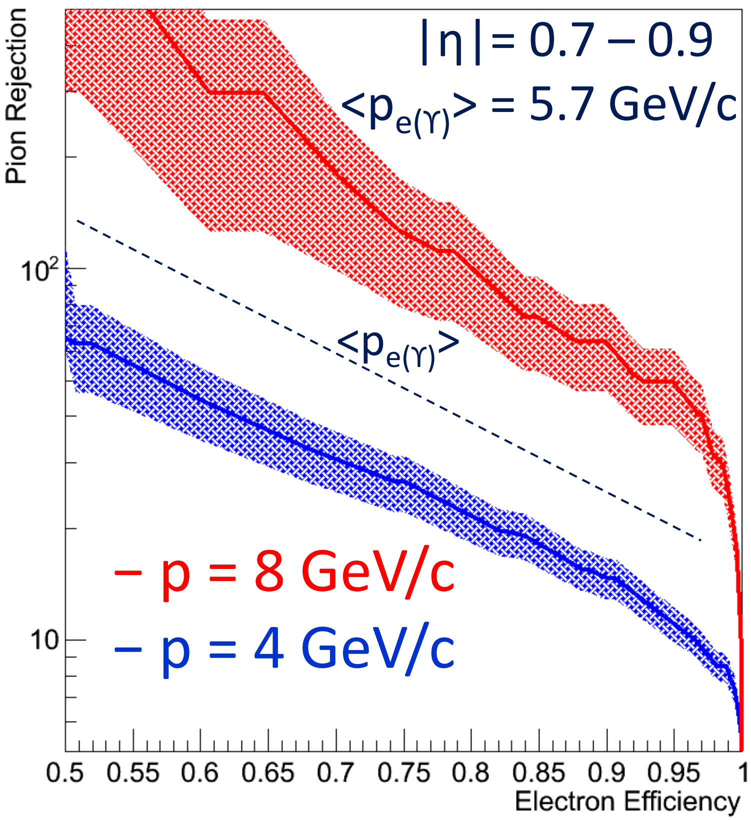
Summary

- On-going R&D on projectivity
  - On-going R&D make it more hopeful to construct 2-D projective EMCal to improve key eID performance in forward rapidity
  - Will import CAD layout to Geant4 so we could simulate the 2-D projective EMCal in sPHENIX
- Multiple TODO tasks welcome volunteers
  - A few described in the last section
  - Test Anti-kT based clustering using fastJet code with Molier radius as R
  - Evaluate the EMCal performance in full event physics simulations, (e.g. Upsilon VS background)

Extra Information

Momentum distribution of Upsilon Electrons, With thinner SPACAL + background sub. + NON-PROJECTIVE



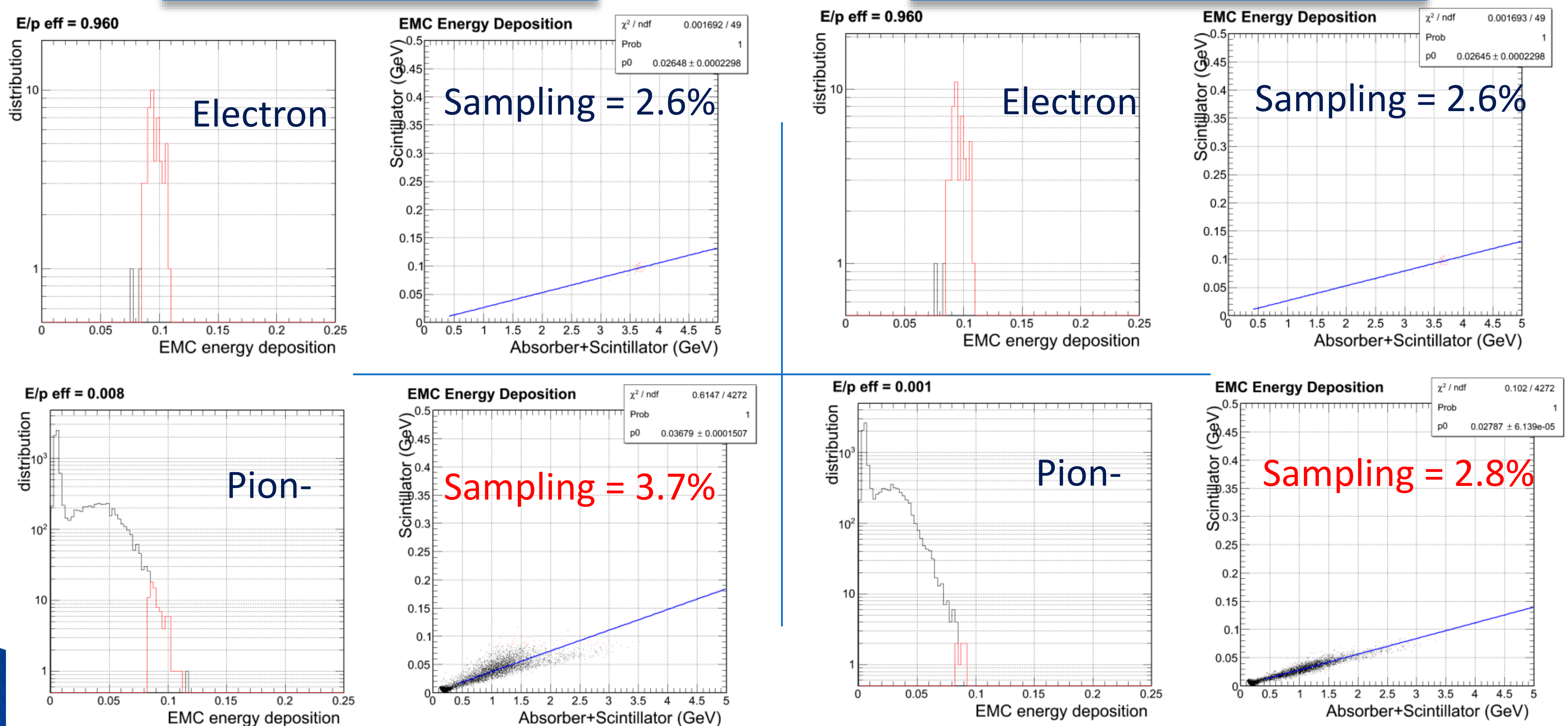


Implementing Birk's law

- Available now in G4hit level
- Could significantly affect e/h for both EMC and HCal

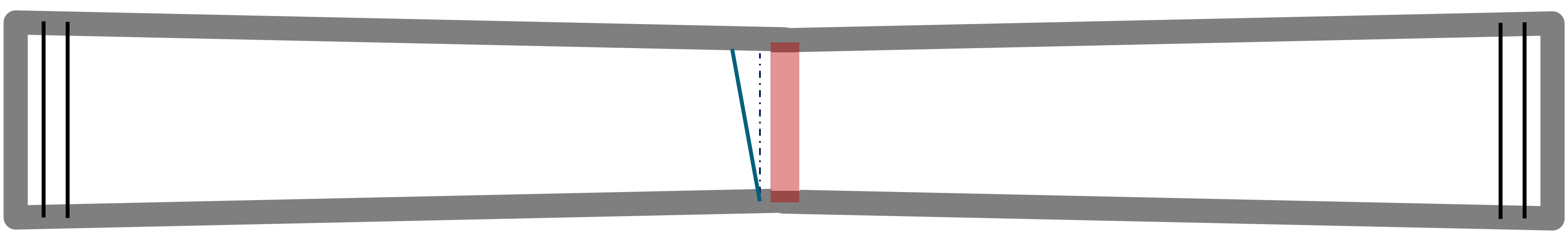
Sum energy deposition

With scintillation light model



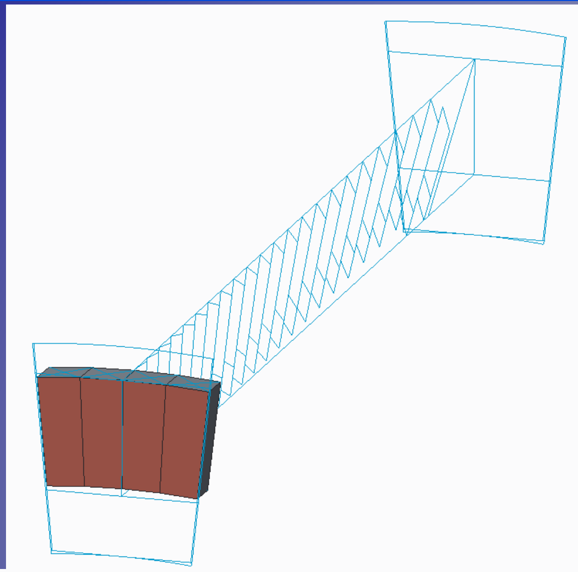
Next: constructing 2D tapered modules

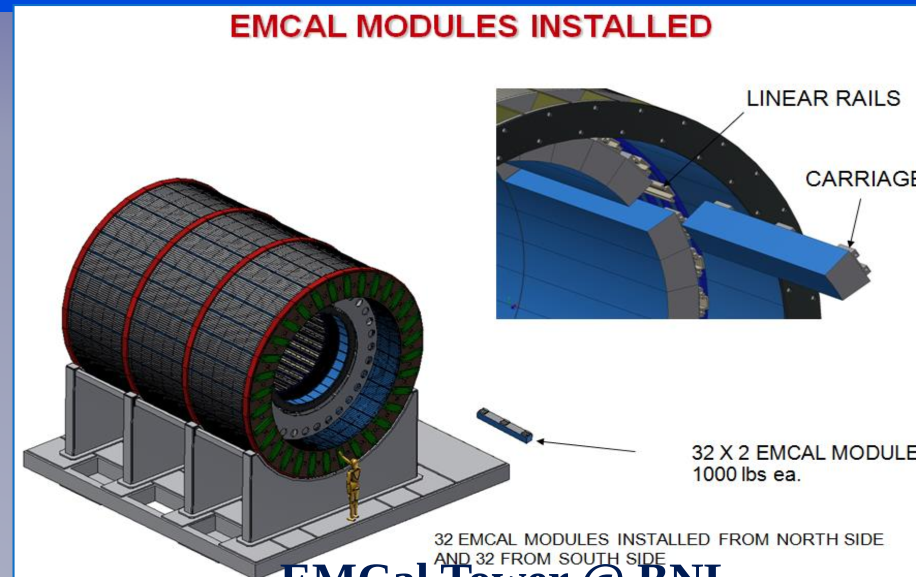
- Exploring first 2-D tapered SPACAL in the world
- From the Dec trips to UCLA, building 2-D tapered modules seems plausible but need to be tested. Many possible ideas, going to try both at BNL and UIUC (see Anne's talk)
  - Making tapered fiber matrix using a pair of wire screen (last slide)
  - Build double length module then pinch fiber matrix in the middle to make two proj. SPACAL (illustrated below)
  - Pull and squeeze on one side of fiber matrix with the other side fixed
  - Shaving straight modules to taper the sides
  - shrinkable screen,…
- Understand 2-D tapered module in simulation: implement this design in G4, does it deliver sufficient improvement?
- Optimize production technique, transfer the technology to production

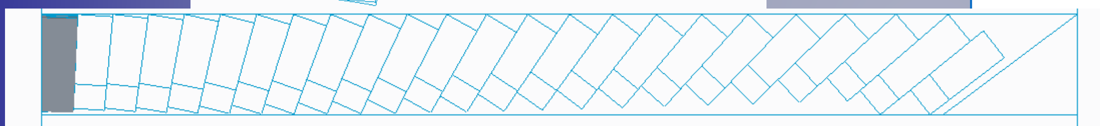


Example of another possible building technique
Discussed in UCLA meetings (BNL, UIUC, UCLA)

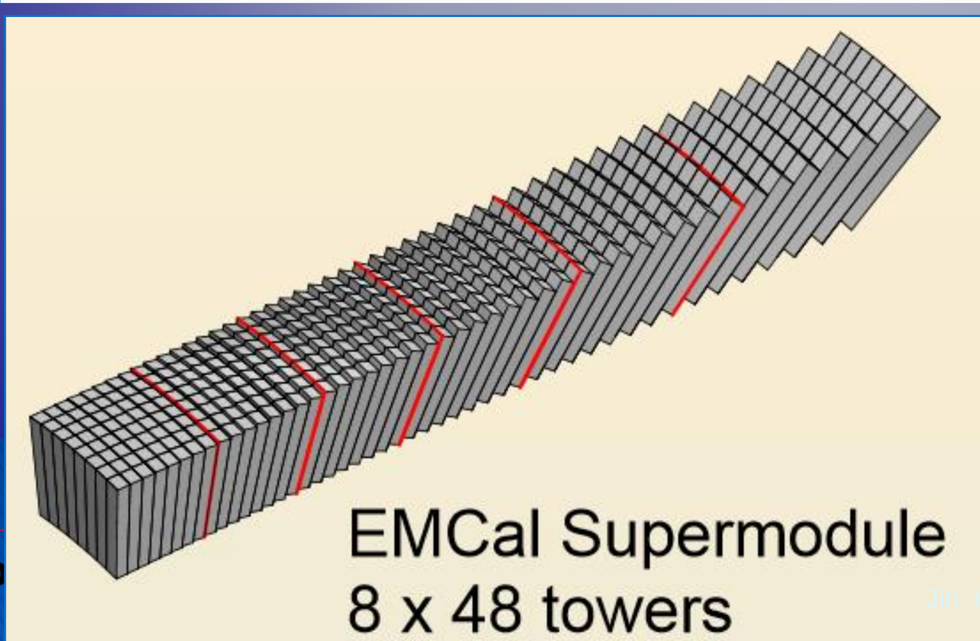
EMCal Design







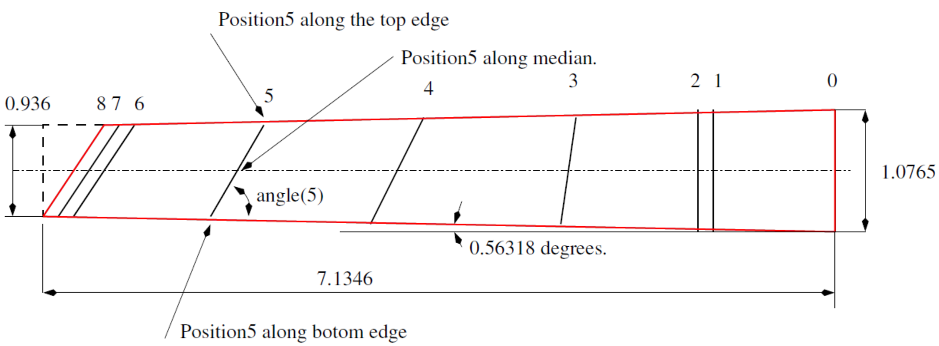
EMCal Tower @ BNL



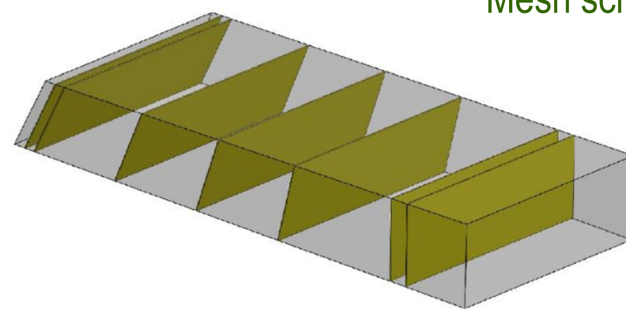
Making Projective EMCal Modules

The current technology developed at UCLA can be used to produce 1D tapered modules

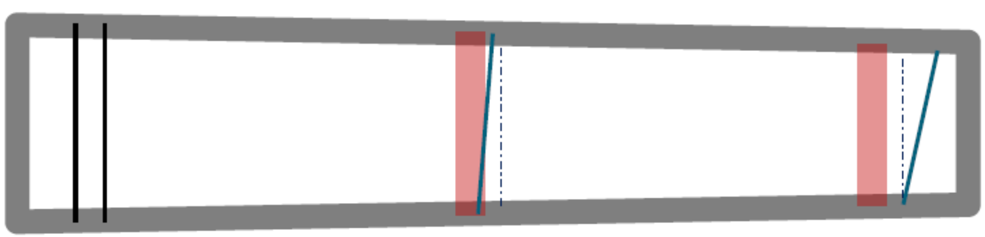
1D tapered module

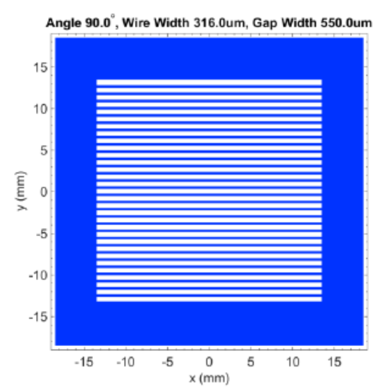


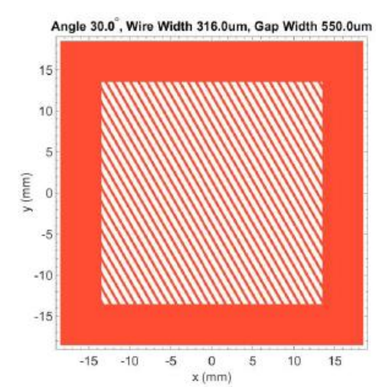
Mesh screens



2D tapered module







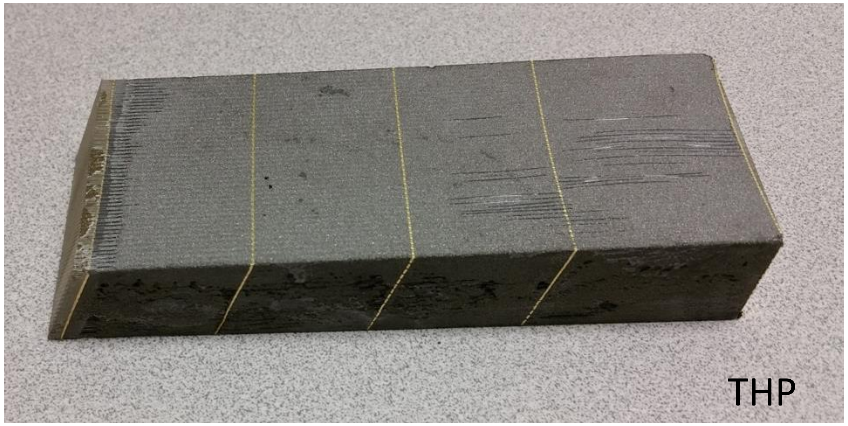
J.Huang
BNL

Two slotted wire frames allow two independent rotation angles

Mass Production of Modules

- THP has been trying to build 1D modules and has been making reasonably good progress
- Problems with gluing and getting good uniformity and consistency
- Experiencing delivery problems with things like epoxy, meshes, etc.
- However, they have not significantly increased the efficiency for module production beyond what Oleg Tsai has done (still takes more than one day per module)
- Goal is to first produce acceptable modules and then try to improve efficiency

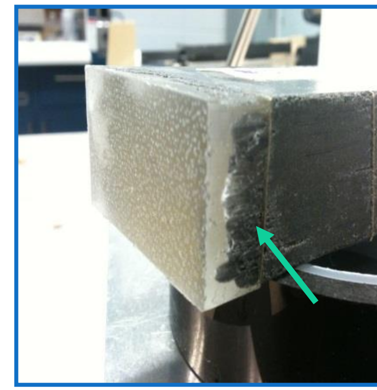
- Once they achieve this, we would then transfer the technology developed at BNL for producing 2D modules to them (→ ~ August)
- Hopefully they would then apply their improved production techniques to produce the 2D modules

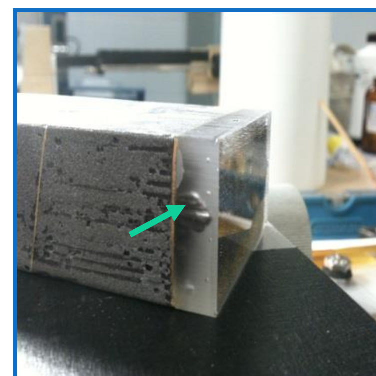


Goal would be to have all modules for prototype(s) by this fall

SPACAL module production at BNL

- We have produced 4 modules at BNL so far
- We are holding off on producing more until the new 2D taper meshes/screens come in, possibly this week
- We have sufficient fiber, tungsten powder, screens, epoxy to produce another 12 modules
- We feel that we have worked through most of the issues and understand the process well
- Some issues that we have dealt with:
  - air bubbles/tungsten powder inclusions in clear epoxy region
  - Full and uniform penetration of epoxy through the tungsten powder
  - Uniform surface characteristics
  - Uniform fiber distribution
  - End surface finish/polish
- One module is currently in the PHENIX IR as part of the SiPM radiation damage testing.



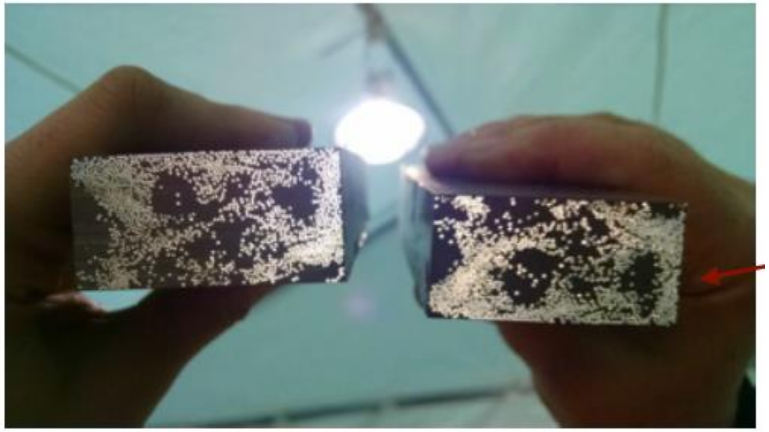


S.Stoll

Module Production at Illinois

Initially started trying to produce 2D tapered modules two at a time (bow tie design)

center of
“bow tie”



- New postdoc Vera Loggins is now working on module design and production. Spent 1 week with us here at BNL
- Currently planning to try and produce 1D modules using Oleg’s technique as a next step

Scintillation Light Model

- In current simulation of sPHENIX calorimeters, energy from calorimeter is sum of total energy deposition or ionization energy deposition
- As moving towards next-stage more realistic simulations, several experimental factors need to be considered, including ionizing energy loss, scintillating light modeling, transportation of photons, and noise in SiPM
- One addition ready for CVS submission:
  scintillation light modeling [Birk, Phys. Rev. 84, 364, 1951]

$$Light\ Yield \propto \frac{\frac{dE}{dx}}{1 + kB\,\frac{dE}{dx}}$$

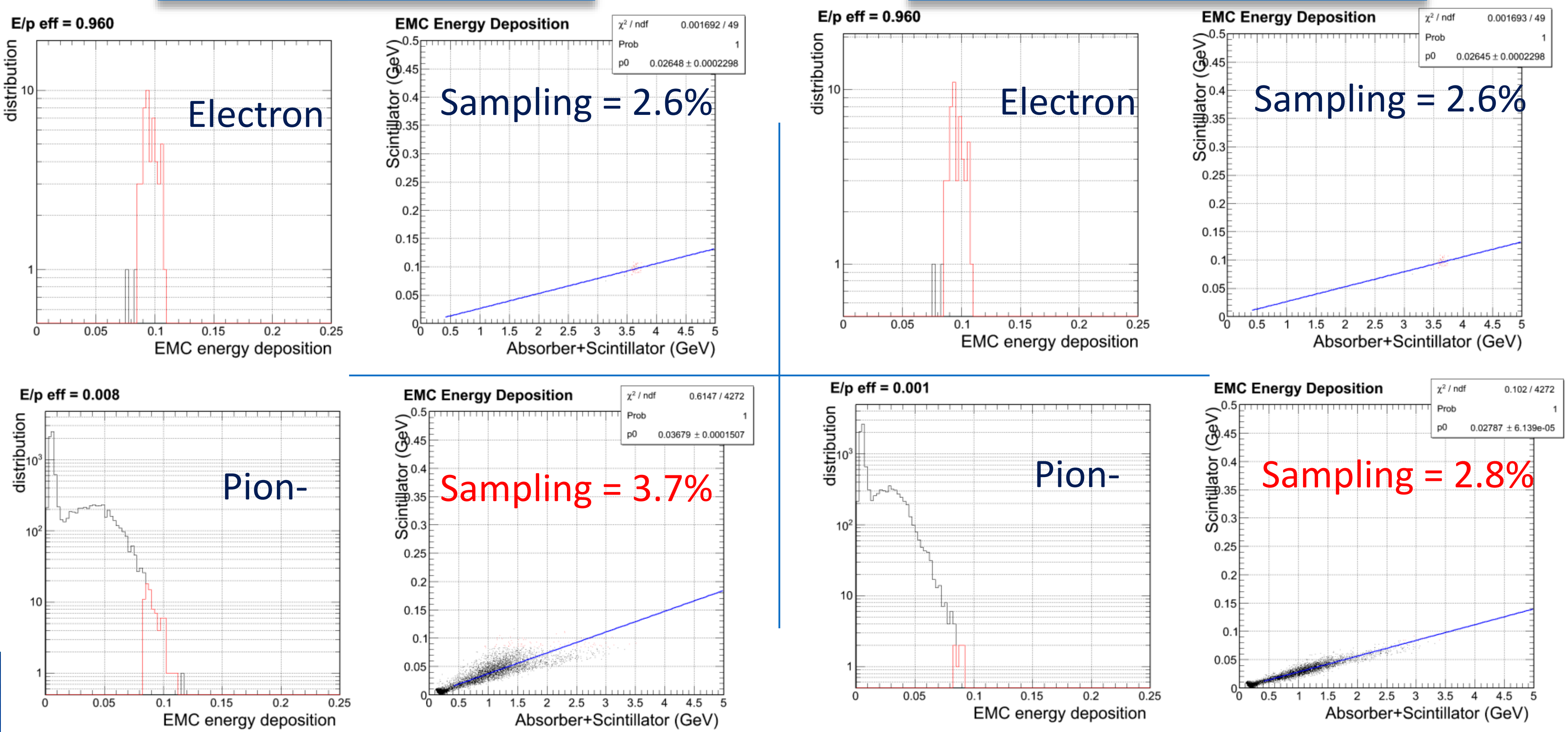
k_B~ 0.126 mm/MeV [arXiv:1106.5649v2]

Implementing Birk's law

- Available now in G4hit level
- Could significantly affect e/h for both EMC and HCal

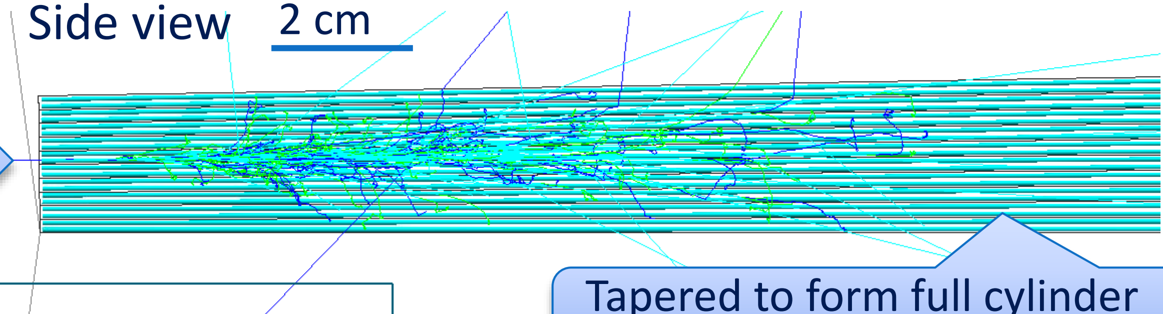
Sum energy deposition

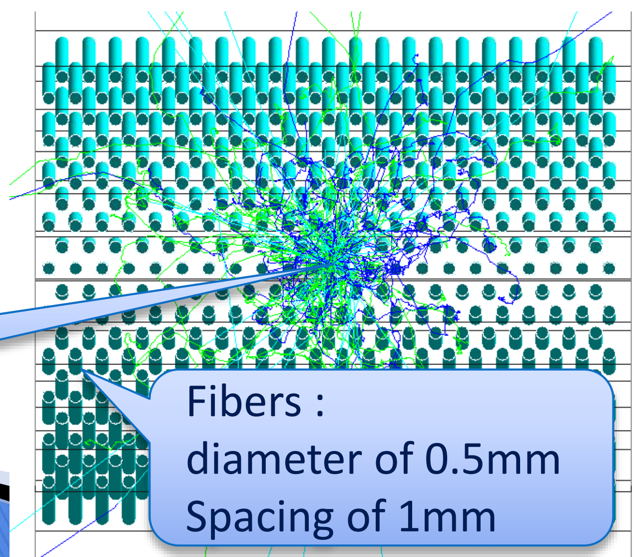
With scintillation light model



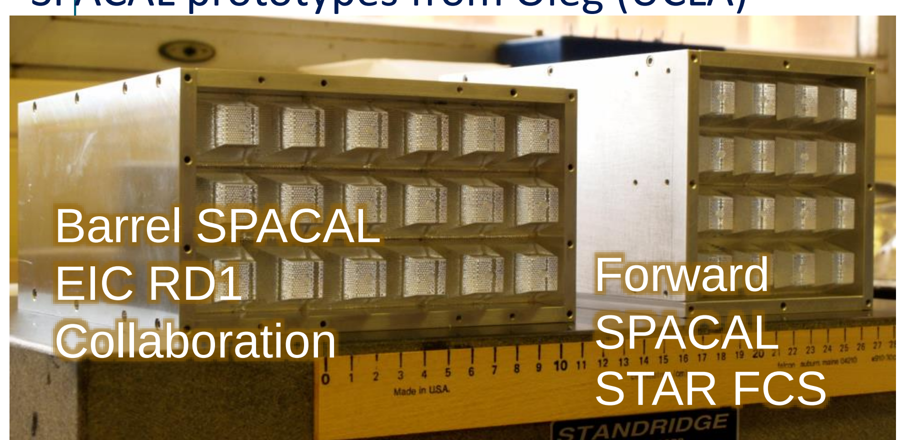
SPACAL simulation

- SPACAL implemented in sPHENIX simulation framework
  - Thanks to reference model from A. Kiselev (EIC taskforce & EIC RD1)
- 10 GeV electron shower in a single SPACAL module shown
- Covered full azimuthal and $|\eta|<1.1$ in sPHENIX (Page 4)





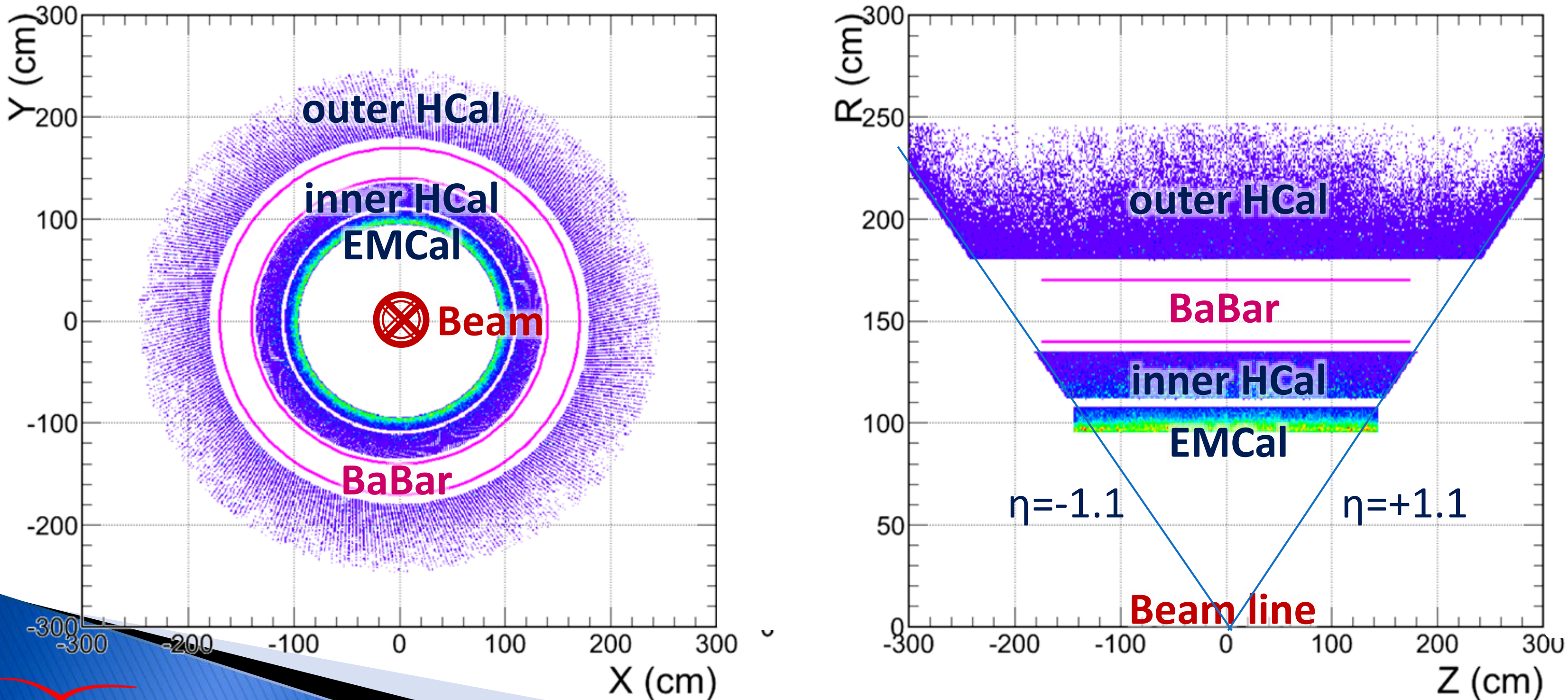
SPACAL prototypes from Oleg (UCLA)



sPHENIX Calorimeters

- EM calorimeter (EMCal) : 18 X_0 SPACAL
- Inner hadron calorimeter (inner HCal) : 1 λ_0 Cu-Scint. sampling
- BaBar coil and cryostat. (BaBar): 1 X_0
- Outer hadron calorimeter (outer HCal) : 4 λ_0 Steel-Scint. sampling

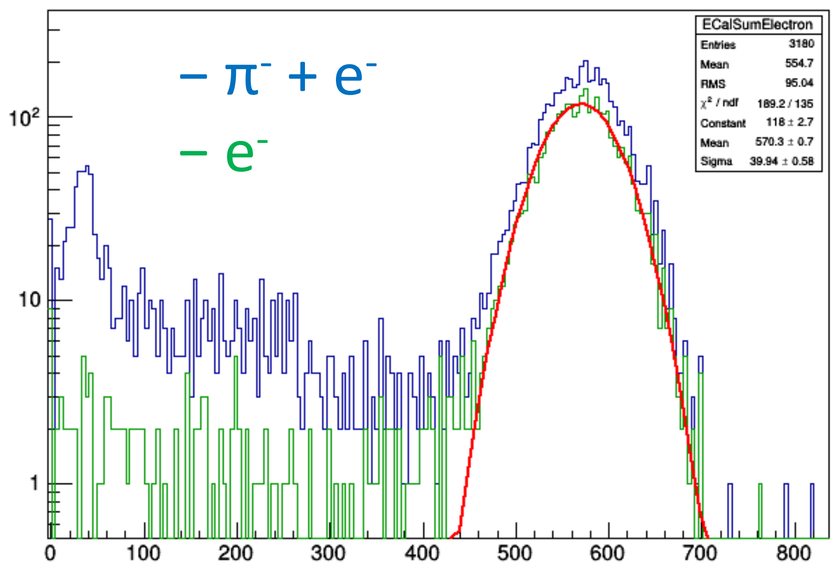
Calorimeter energy distribution in full event central AuAu collisions and realistic magnetic field



Final check should be against data

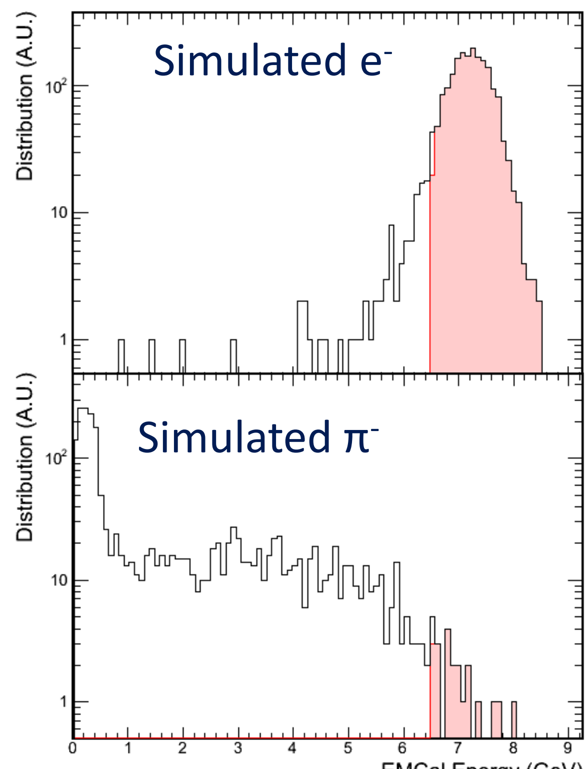
- Next steps will be quantitative check against beam test data

Courtesy : O. Tsai (UCLA)
SPACAL prototypes in 2014 Fermilab beam test
Energy sum for 5x5 towers
(asking for separated spectrum)



Sum energy in 5x5 tower (A.U.)

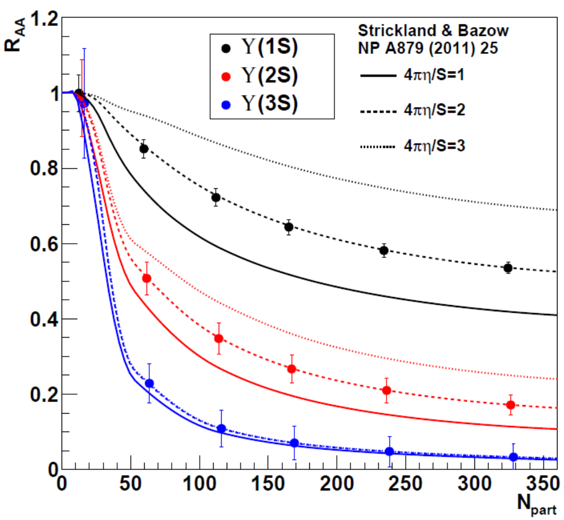
sPHENIX simulation of 8GeV e/π^-
Energy sum for 5x5 towers
(w/o scint. light modeling)



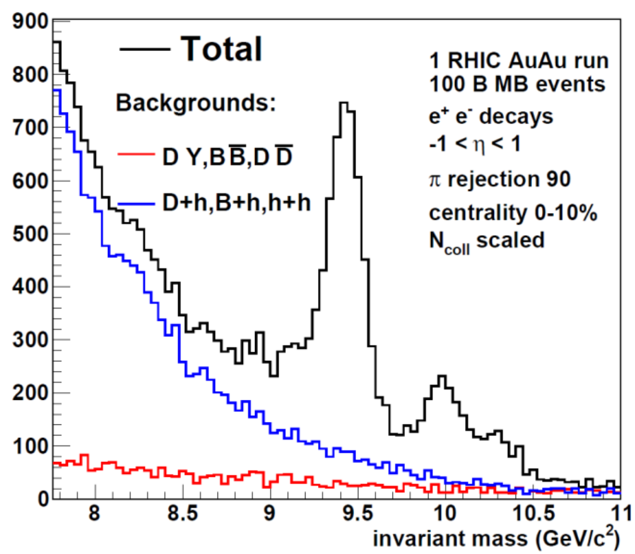
sPHENIX EMCal

1. Upsilon electron ID – main driving factor
2. Direct photon ID
3. Heavy flavor electron ID
4. Part of jet energy determination

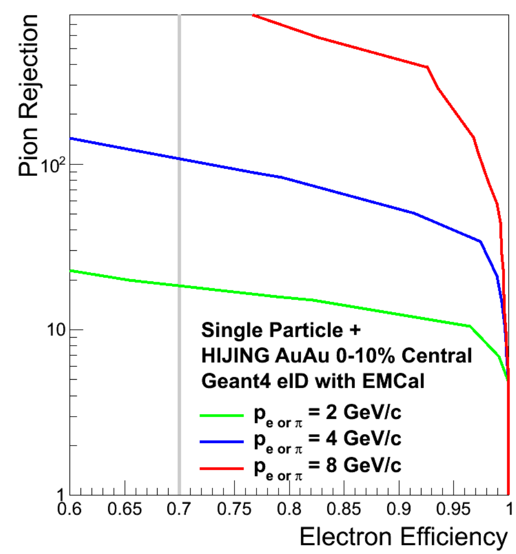
Upsilon R_{AA}



Hadron VS Upsilon



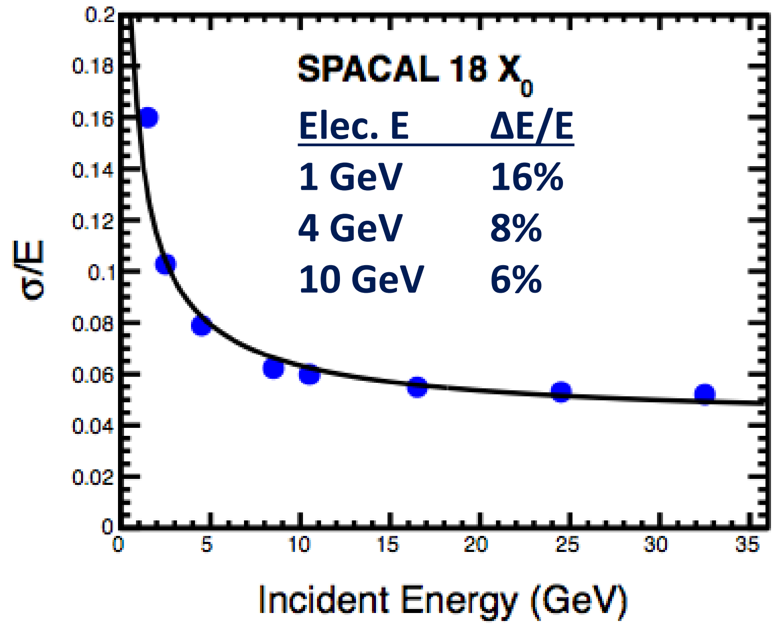
Hadron Rej. ~100:1



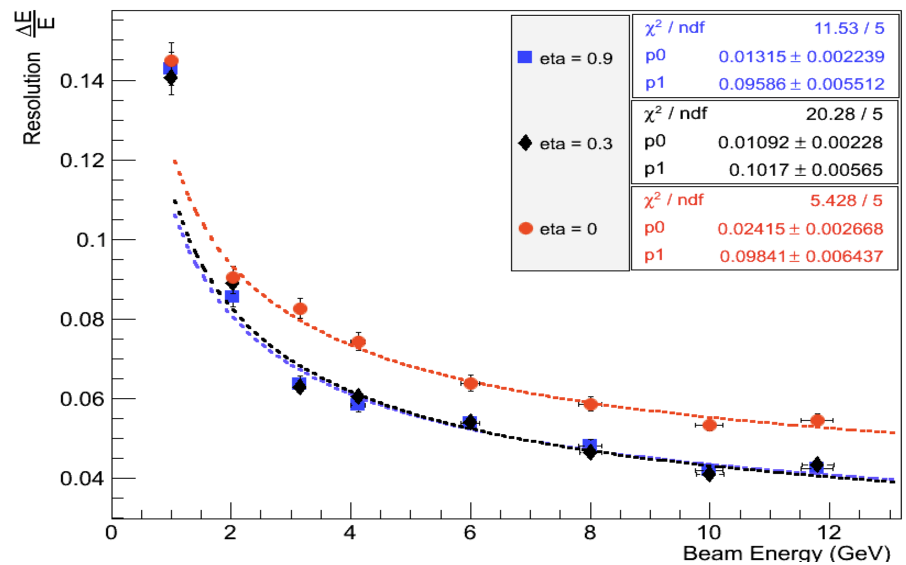
SPACAL study (1): electron resolution

- Electron resolution → Electron PID efficiency
- Compared to simulation from EIC RD1 collaboration and beam test
- Consistent in general; **more work on noise and cell structure simulation**

sPHENIX simulation
5MeV(scint.)/tower zero-suppression



EIC RD1 study
FermiLab beam tests



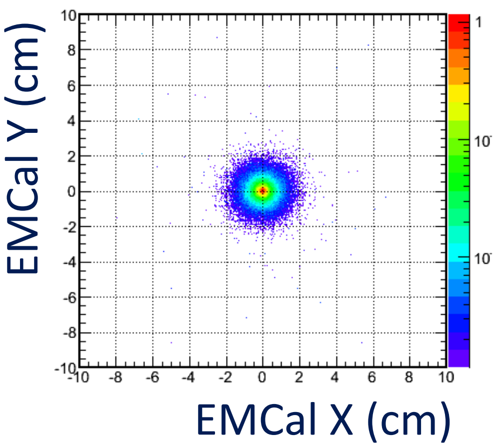
Courtesy: A.Kiselev (BNL)
DIS2014

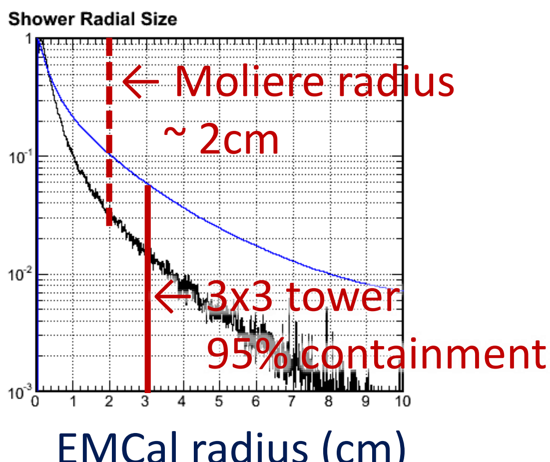
SPACAL study (2): spatial response

- Spacial containment of showers → size of cluster

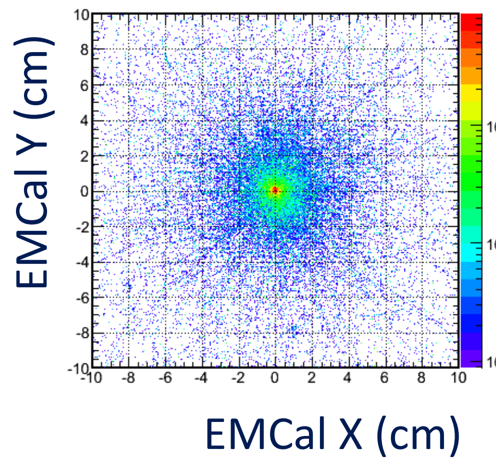
- Energy deposition (A.U.)
- Percentage outside radiu

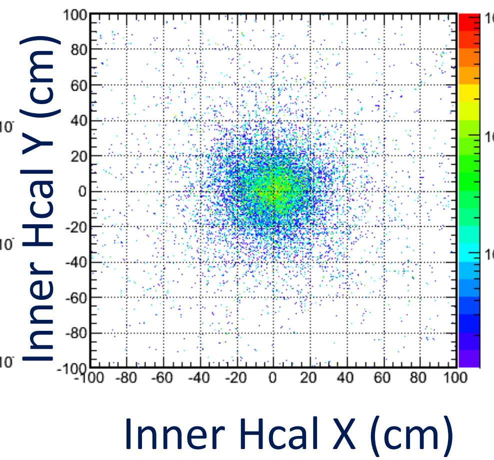
4 GeV Electrons

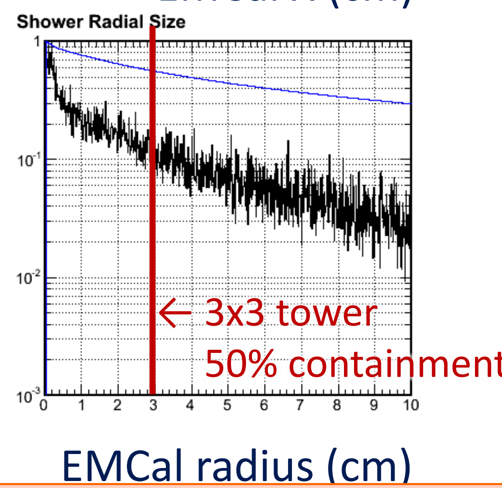


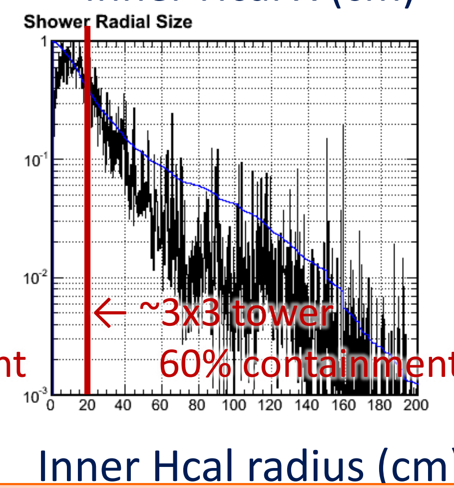


4 GeV Pions, that **passed E/p cut**





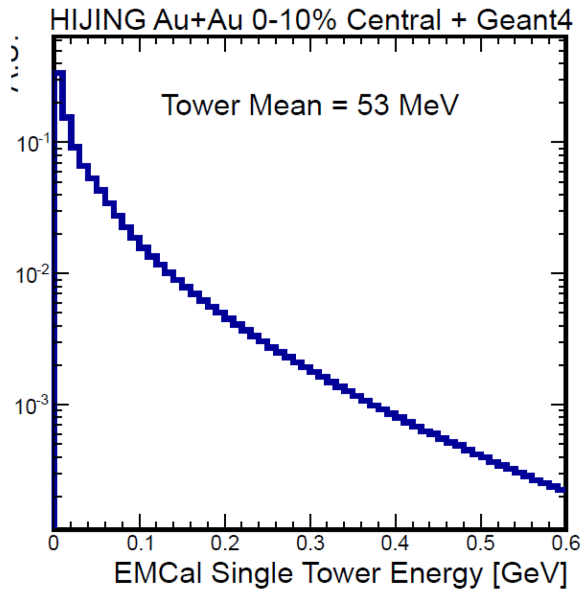


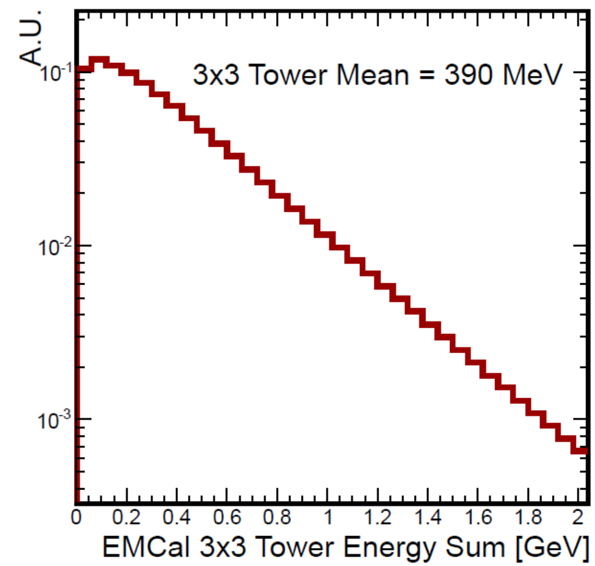


Outtie-HCal has much larger spread. See backup 1

Event background distribution in Central AuAu

- Study of electron ID in central AuAu
  1. Embed single particle simulation to full event Hijing simulations (0-4.4 fm, ~0-10% Central, in full magnetic field)
  2. Get rejection through re-optimized EMCal+ HCal cuts
- EMCal background is moderate
  - Most hadron particle leave MIP energy in EMCal
  - Tight EMCal Moliere radius
- **Inner HCal background is significant, render it less useful in electron ID** (compared with an alternative tighter E/p cut from EMCal)



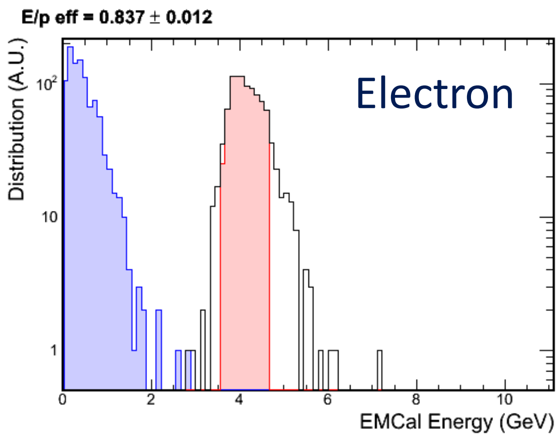


eID in central AuAu, central pseudo-rapidity

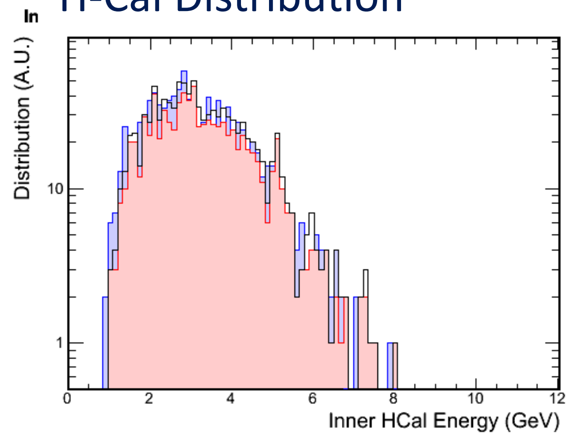
4GeV electron and pion-, |η|<0.2

EMCal tower cut : R<3cm, Hcal cut : R<20cm

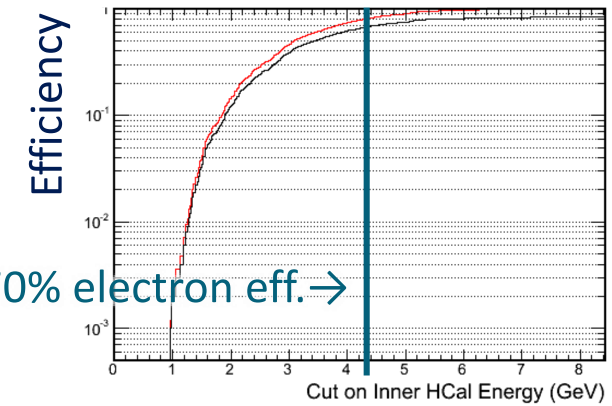
- Hijing background (AuAu 10%C in B-field)
- all c(w/ embedding)
- with EMCal E/p cut (w/ embedding)

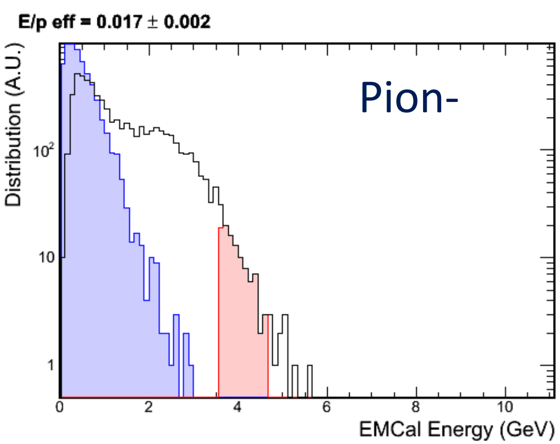


H-Cal Distribution

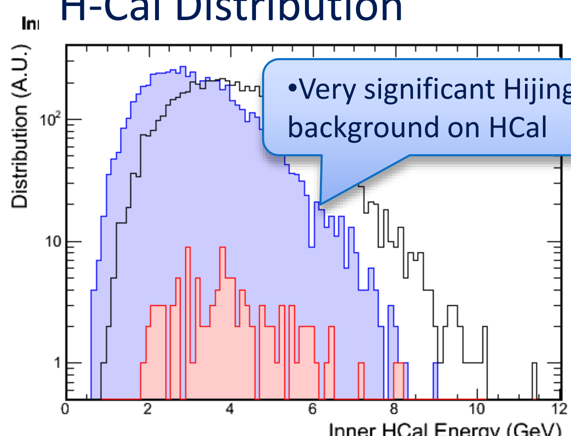


H-Cal Cut Efficiency



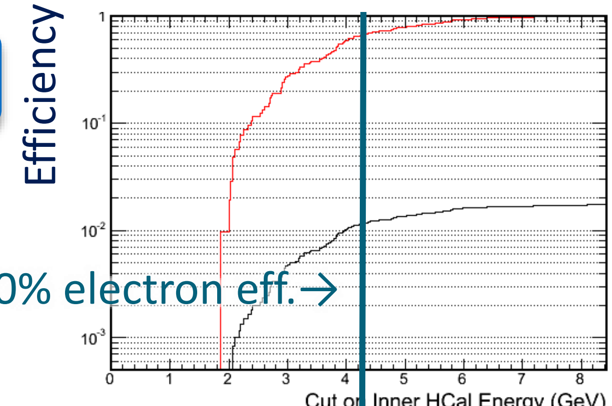


H-Cal Distribution



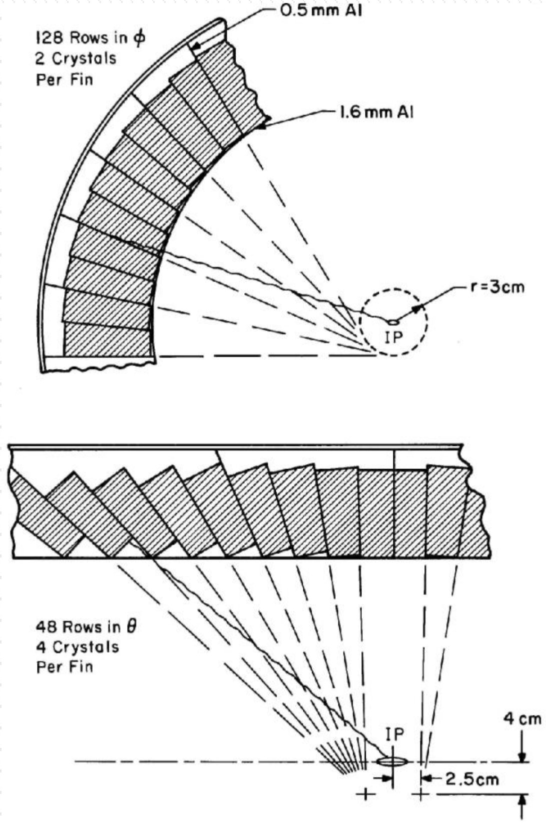
•Very significant Hijing background on HCal

H-Cal Cut Efficiency

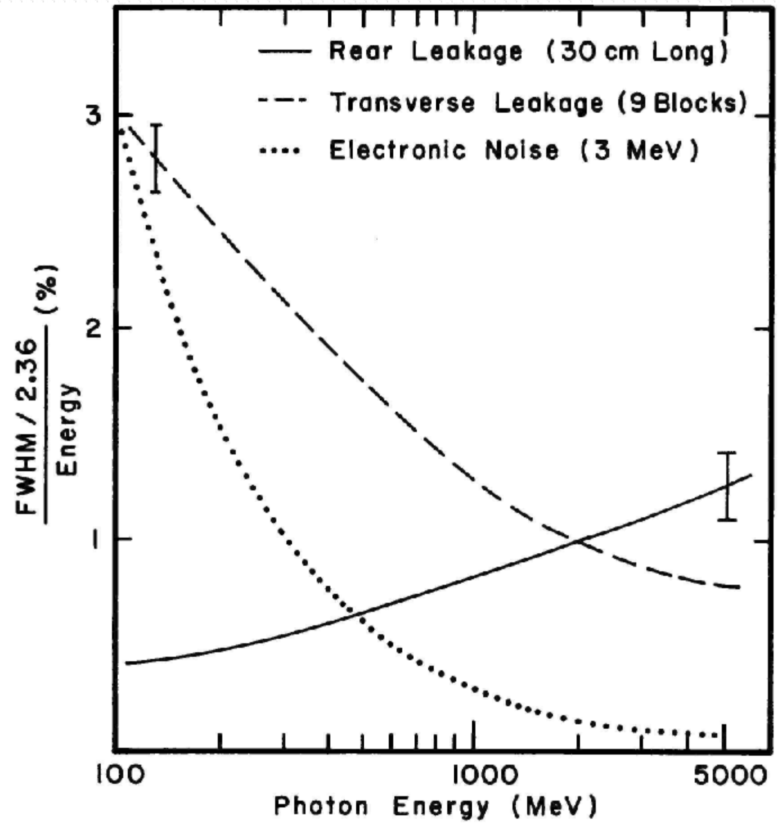


- Additional rejection of x2 from H-Cal
- **Total rejection ~90:1**

Cracks and steps are not new problem
See also projective crystal calorimeters



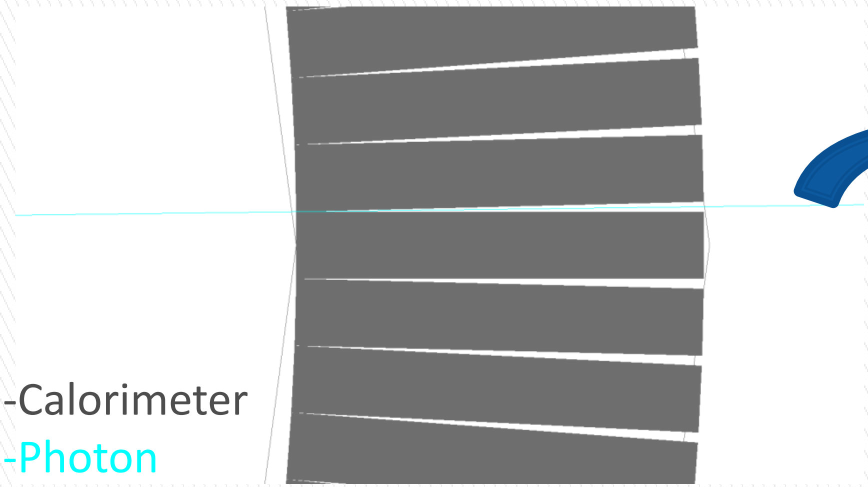
CLEO II EMCal Design



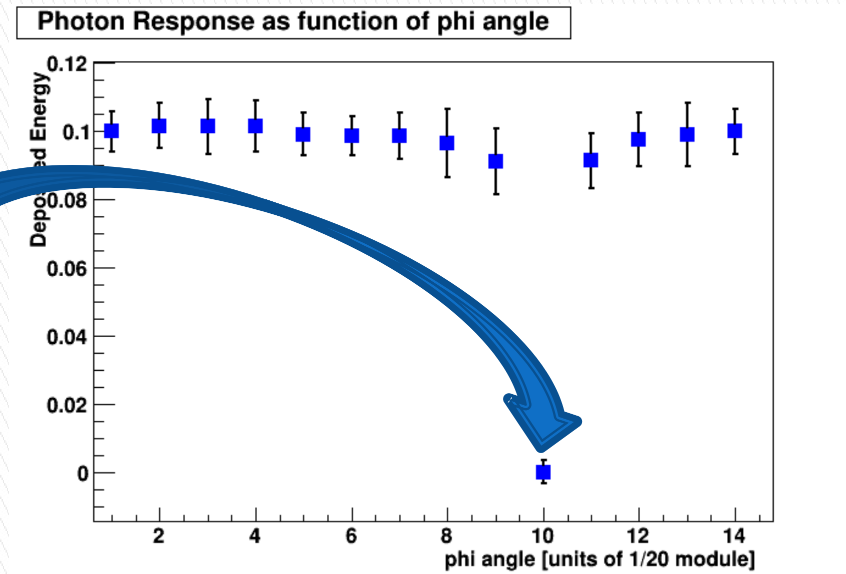
In contribution to energy resolution

Stolen from QWG3 Topical School. B Heltsley. Oct 2004

No tilt angle, no magnetic field = leakage



-Calorimeter
-Photon
-Lepton
-Hadron



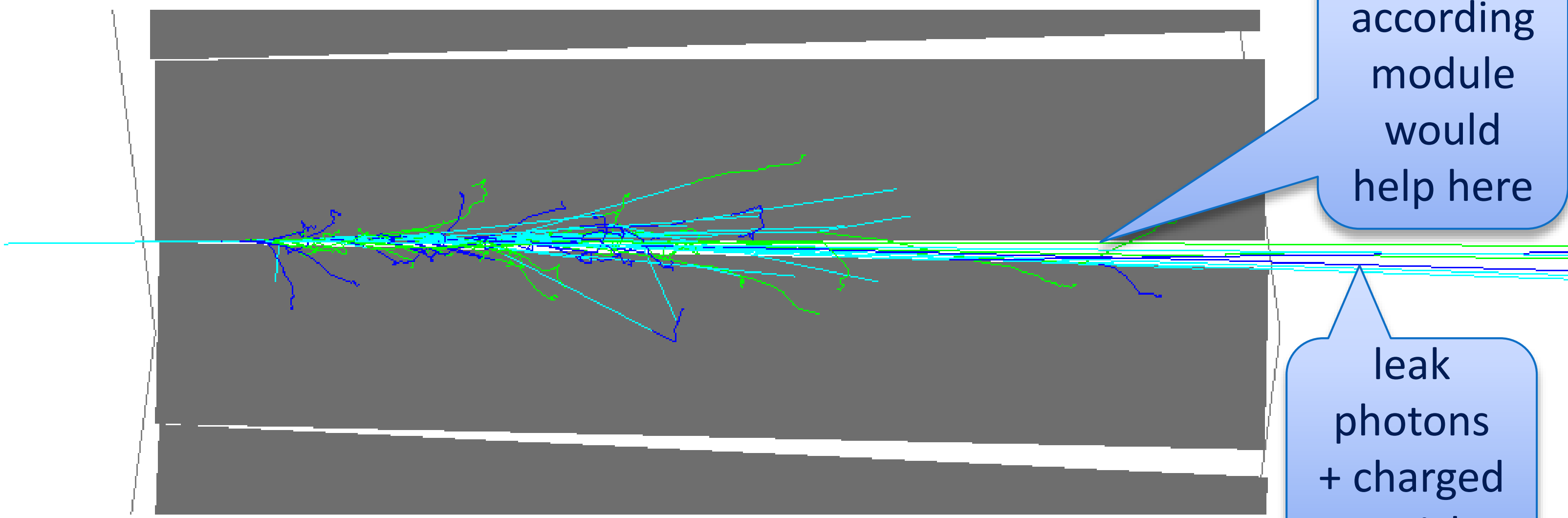
4GeV photon tunnel through the gap

Energy deposition VS hit location (from Martin P.)

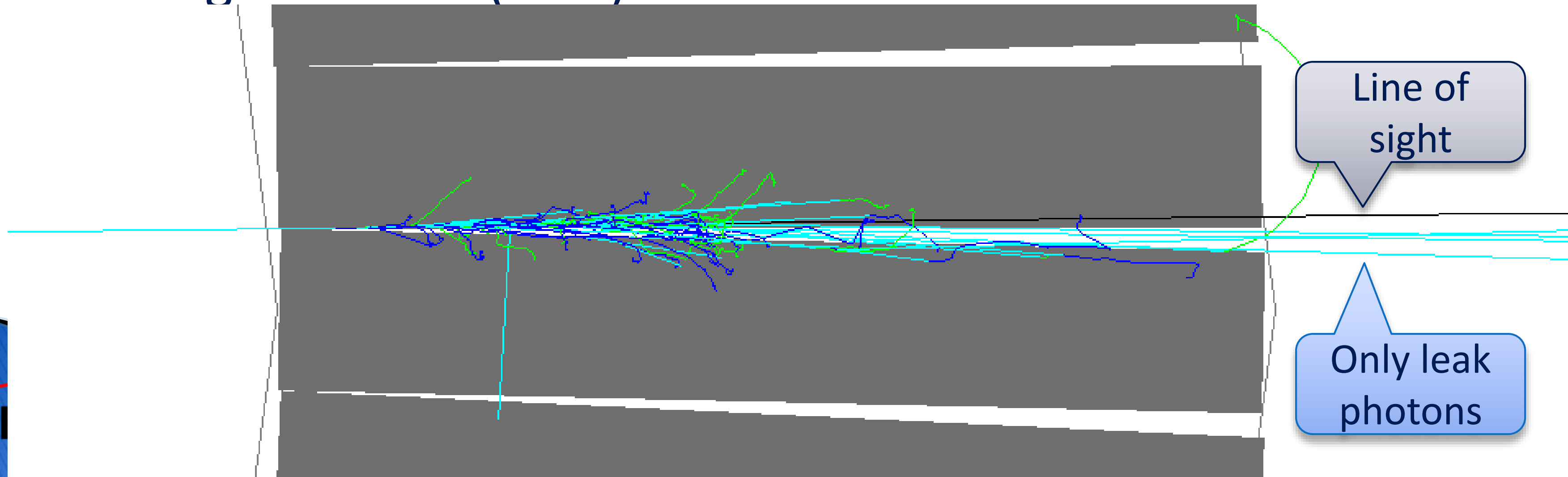
23mrad tilted blocks (no line of sight)

- With no magnetic field

-Calorimeter
-Photon
-Lepton
-Hadron
-Geantino



- with magnetic field (1.5T)

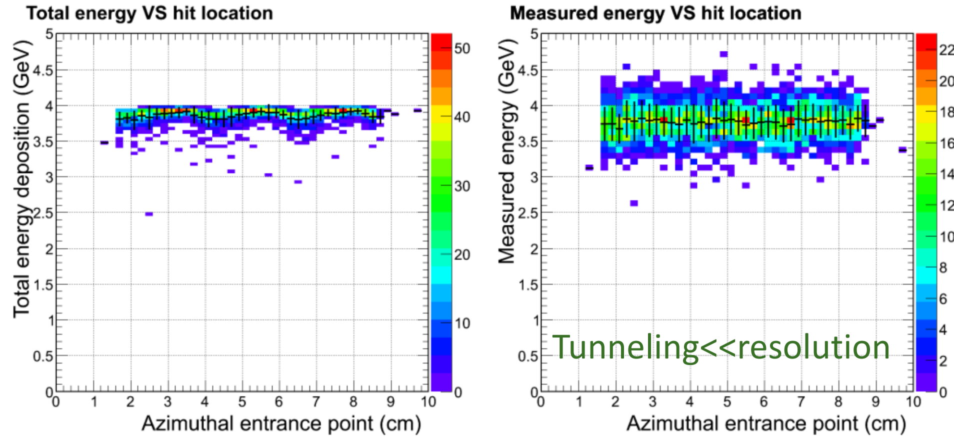


Over tilting of 196 mrad

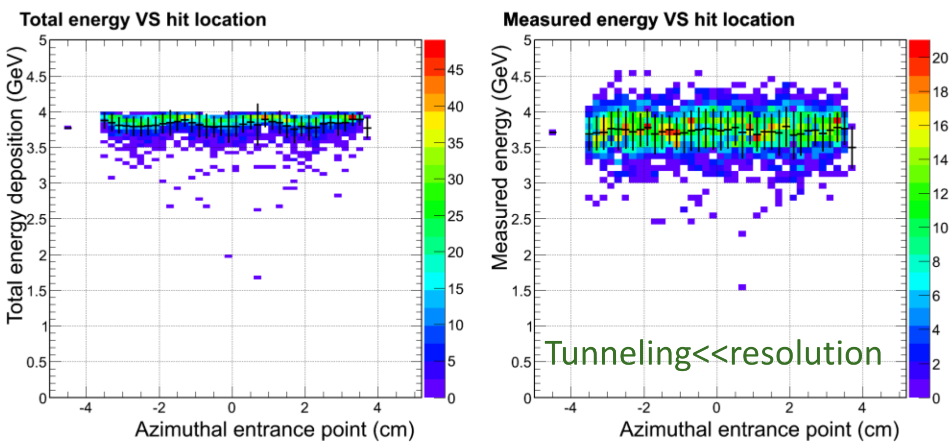
Further tilt to the block diagonal angle

- Expect to observed non-projectivitiy effect in azimuthal
- Solved the uniformity problem for Upsilon electrons
- Uniformity for other particles still need to be better understood

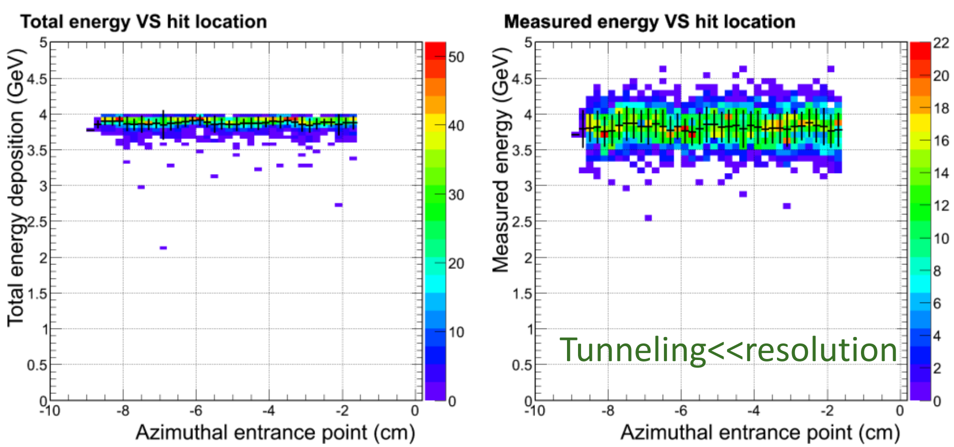
Lepton bended towards from gap



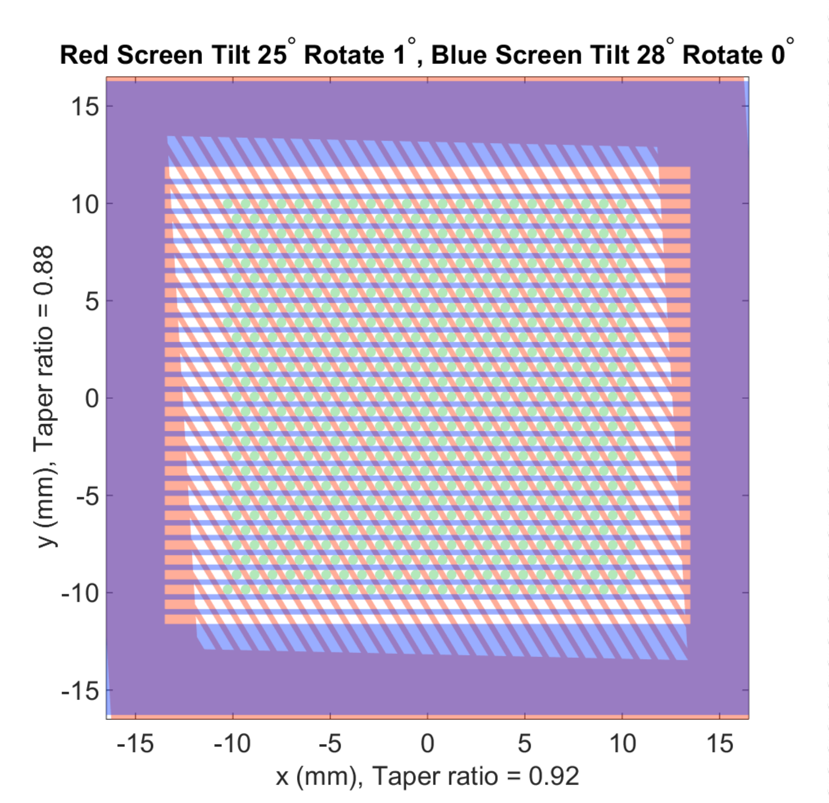
Photon

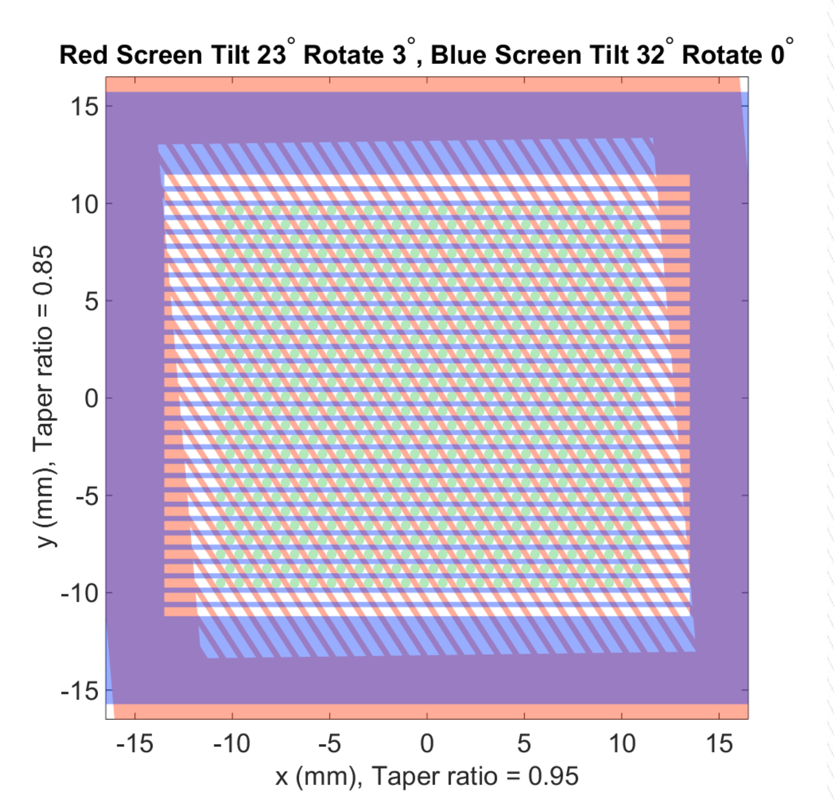


Lepton bended away from gap



Flexible taper ratio (different module for different eta rings)





92% - 88% taper

95% - 85% taper

PHENIX

Early SoLID Shashlyk EMCal simulation

1.5 T magnetic field along direction of EM shower